Tooth wear

prevalence and occlusal factors

Arie van 't Spijker

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General introduction

Introduction

Tooth wear is a subject gaining increased attention in both general dental practice and dental research. For a long time, it has been an uncultivated area in dentistry because dental care was predominately facing the major dental diseases of caries and periodontal disease. In Western countries the caries epidemic decreased during the last decades and meanwhile the non-bacterial deterioration of tooth tissues by wear caught the attention of the dental profession in this part of the world [1].

Mechanically loaded objects will eventually show signs of wear. Tooth wear due to normal functioning by chewing therefore is regarded as a natural phenomenon. Archaeological research and excavation of (historical) burial sites revealed wear facets on almost all the teeth found in human remnants and the degree of tooth wear is often used as an indicator of the age of the examined individual [2,3]. Tooth wear can even be regarded as a mechanism of adaptation or compensation. For instance, if specific teeth undergo changes in tooth position due to mesial drift, flatting of their tooth cusps may occur in order to maintain habitual occlusion or jaw movements [4]. Despite the normality of the phenomenon, there has been a drastic increase of professional attention for tooth wear. Today dental clinicians have the (common) opinion that the prevalence of tooth wear is increasing, because of a high incidence of non-physiological tooth wear. Also the prevalence of extensive wear is thought to increase substantially especially erosive tooth wear at young age [5,6].

As a consequence of the interest into tooth wear, the volume of tooth wear related research presented in the dental literature expanded substantially during the last three decades. Also the number of conferences and post graduate courses addressing this subject increased. In a superficial Pubmed search it appeared that in the 1990s the annual number of publications on tooth wear was approximately 100 papers, two decades later it had passed 300 publications per year. It is unclear whether this increased professional attention arises from the observation of a true increase in the prevalence of (severe) tooth wear or whether it is based on a fictional observation due to a lack of reference data from the past. Apart from this aspect, there is much debate about the backgrounds of tooth wear in terms of wear mechanisms and etiological factors, as well as threshold values of worn tooth tissue to initiate the clinical reconstruction of teeth. Above all, management strategies for tooth wear are debatable and evidence based therapies are not available. This makes the topic of tooth wear a relevant subject for both researchers and general practitioners.

Wear mechanisms

Wear in a tribological context is defined as the progressive loss of material from the operating surface of a body, caused by relative motion (friction) at the surface [7]. In the dental context this type of wear includes *attrition* and *abrasion*. Another wear phenomenon is the dissolution of the surface of an object by means of fluids. In dental *erosion* this is caused by acid dissolving hard tooth tissue [8].

As a consequence, dental erosion has been defined as the irreversible loss of dental hard tissue caused by a chemical process not involving bacteria [9]. Dental abrasion is defined as the loss of tooth substance due to friction with a foreign body (e.g. tooth brush), and dental attrition is the loss of tooth substance due to friction of opposing teeth. A fourth term, *abfraction*, has been used to describe wedge shaped cervical lesions as a wear defect. As there is no consensus about the aetiology of these cervical lesions, it has been suggested to use the term *Non Carious Cervical Lesions* (NCCL) instead of abfraction [10].

The appearance of the worn tooth surfaces resulting from the various types of wear differ. In case of friction the surface is flattened with sharply defined surface edges whilst in case of dental erosion the surface is not flat per se, and usually shows rounded surface edges [11]. Tooth wear can occur locally, affecting for instance incisors only, but it other cases it may also affect the whole dentition. The distinction between abrasion on one side and erosion and attrition on the other side is that abrasion most often leads to local defects, while the other two forms often have general consequences. Although it appears logical to relate the observed wear pattern to the aetiology, differentiation based only on the appearance of a lesion is difficult. In the absence of any erosive factor in the anamnesis and without the eroded type of occlusal surface, observed tooth wear can be related to a high certainty to the mechanical type. However, different types of tooth wear often coincide in a subject and the clinical appearance therefore is diffuse. This underlines the statement that tooth wear should be regarded as a multifactorial phenomenon [12]. Consequently the observed wear pattern in a specific patient can rarely be related to one single specific cause.

Levels of tooth wear

The amount of tooth wear varies from one individual to another and varies in time within one individual, but in most instances it correlates with age [13,14]. So-called *normal tooth wear* is a gradual thinning of the enamel layer over the years without or with exposing the dentin underneath. In cases of attrition the first signs of dentin exposure occur most often on the tip of cusps of first molars and canines, while erosion expresses itself at the occlusal surfaces of lower molars and palatal surfaces of the upper posterior teeth [15]. The gradual loss of tissue at higher age does not necessarily lead to disturbance of the chewing function of the dentition or to sensitivity of teeth [16], although tooth wear can have an impact on patients satisfaction with their dentition [17]. In *advanced tooth wear* the enamel layer has been passed and dentine is firmly exposed. In teeth with dentine exposure due to tooth wear, internal deposition of so-called secondary dentine may prevent increased sensitivity of the teeth. The formation of such a dentine layer is considered an adaptation mechanism protecting the tooth pulp [18]. The loss of occlusal surface of a molar or premolar might be compensated by eruption of the affected tooth or its antagonist, thereby outweighing the vertical loss of tooth tissue. The loss of vertical dimension may also be compensated by growth of the alveolar bone [19]. This phenomenon can be observed by studying the shift of the attached gingiva of the concerning teeth [20]. Adaptation to tooth wear not only occurs through compensating eruption or internal dentine apposition, but may also result in adaptation of the masticatory muscles or remodelling of the temporomandibular joint [4].

Tooth wear is regarded *pathologic* when the process has a pace that makes the lifetime maintenance of natural teeth in their functions (chewing, speech and esthetics) uncertain or even impossible [21]. In case of pathological tooth wear the normal adapting processes are not able to compensate the tissue loss in the same pace. Excessive wear of enamel or dentine may cause pain or sensitivity of teeth, disturbed appearance, impaired function, or teeth may show mobility eventually leading to serious consequences for the involved individual [22, 23,24]. If the loss of vertical dimension of the opposing jaws is not fully compensated, the transversal and sagittal curves may change, thereby altering the dynamic occlusion and chewing movements. Further overloading of teeth, even during normal chewing cycles, may result. In these cases it remains uncertain if the compensation curve (Christensen phenomenon) is maintained [25,26,27]. Additionally pathological attrition resulting from clenching and/or bruxism habits, might affect the temporomandibular joints. For this reason severe wear is often related to TMD problems [28].

Considering the possible effects of pathological tooth wear, treatment should be adequately initiated. However, it will always be very difficult to discriminate between physiological and pathological tooth wear, due to the large variety in clinical appearances and the variety in burden patients report. Since the knowledge about the course of tooth wear over time is not established, the general practitioner has no indication as to monitor or treat severe cases of tooth wear. Also the role of co-factors in cases of severe wear has not been established yet.

Recording of tooth wear

It had been stated that the prevalence of tooth wear has increased over the last decade [29]. Reported causes for this increase, are the erosive challenges in modern life (diet, environmental factors, reflux) and the fact that more people retain their teeth at high age. As a result teeth showing age related levels of wear, and extensive wear on teeth will be more present.

Tooth wear measurements for prevalence purposes (cross sectional studies) are mostly based on indices. Multiple indices have been developed, such as the index according to O'Sullivan, O'Brien, and Lussi [230]. A well known and often used index is the *Smith and Knight Tooth Wear Index* in which teeth are graded on a 5-point scale, where "0" is no wear, and "4" is almost completely worn down [31,32]. With the use of a scale with relatively large intervals such as the *Smith and Knight Tooth Wear Index*, small differences will not be noticed in longitudinal studies. Some other indices are designed to relate the clinical appearance to *aetiology* (e.g. erosive wear), making it difficult to compare the results of those studies to *multifactorial* wear studies. Also the dimension: “time” is lacking in cross sectional studies, making this qualitative method not suitable to mark the reported wear as *pathological* of *physiological*. None of the available indices relate the wear status with the functional demands of an individual. Dentine exposition appears to be a clear landmark in the description of tooth wear, but although dentine exposition is often used as threshold for intervention, most indices do not define values for intervention.

Since the 1970’s efforts have been made to quantify tooth wear. Problems that had to be encountered were the precision of the replication technique, the lack of precise and stable reference points, problems in repositioning, low accuracy in measuring, and high standard deviations in both measuring results and biological range. Lambrechts *et al* pioneered in quantifying tooth wear in vivo, using a replica technique, and measuring height differences with the use of a stereomicroscope and a camera [33]. They found an average annual vertical loss of enamel of 15 μm at premolars and 29 μm at molars. In order to reach an exact superimposition, small amalgam fillings were placed. One of the other issues remaining in this method was the accuracy of the replication technique. Other researchers claimed that apart from the necessary fillings, the technique as used by Lambrechts *et al*, was too expensive and required high levels of expertise.

Profilometry by the use of a stylus was applied in several studies, and showed more errors compared to Scanning electron microscopy (SEM), probably due the morphology of the stylus. SEM on the other hand had its disadvantages by the need of complex software, and a low precision of hardware components [34].

Optical techniques such as reflex microscopy and Moiré contourography proved to be accurate and objective, but still were very time consuming and limited to small amounts of wear [35,36,37]. Laser profilometry further improved the performance, but also stable reference points and the use of a replication technique were the crucial factors [38].

The use of direct intra-oral scanners primary designed for the productions of restorations, appeared to be suitable for direct in vivo wear measurements. This method is still developing, and subtraction of the two scans appeared to be complicated since data could not be exported for assessment. There is an obvious need for this scanning technique for research purposes as it has clear advantages: no replicas are needed and scanning directly makes the procedure less uncomfortable for patients. The main question still remains if stable reference points can be identified in order to have an accurate match of models for comparrison.

Guidelines for intervention

In normal function, antagonizing teeth will have intermittent occlusal contact during chewing cycles, causing physiological, natural attritional wear of the occlusal surfaces. This is a physiological process, resulting in a less steep cuspal slope over the years [13,14,24,39,40].

When describing tooth wear, a differentiation should be made between tooth wear as a description of the *mechanism* (the loss of tooth substance *occurring*), and wear as a description of the *status quo* of the teeth (the amount of loss that *has occurred*). This might cause confusion at the intervention decision. On the one hand, intervention in the affected dentition could be intended as a strategy to *prevent* further loss of tooth substance and on the other hand as the strategy to *restore* affected teeth. Tooth wear usually shows a slow progression, and detrimental effects are only obvious when prevention is applied (too) late. In particular generalized tooth wear, affecting occlusal surfaces confronts the dentist with challenges in treatment and treatment planning. Occlusal reconstructions may be necessary in both the young and elderly individuals, both groups with their own functional and age related demands. Different treatment options are available, but the practitioner's choice is usually based on the clinical experience of "specialised" colleagues, and lack of evidence based on research data. Clear guidelines to support decision making in indication, and treatment options in cases of tooth wear, are lacking.

Occlusal schemes

The term: "occlusal scheme" is defined as the form and the arrangement of the occlusal contacts in natural and artificial dentitions. Guidelines for the use of specific occlusal schemes in prosthodontic treatment have been dominated for long periods by dogmatic gnathological prescriptions. Although these so-called occlusal concepts lack evidence for many of the claimed cause-effect relationships, they may offer structured methodologies for prosthodontic treatment. For example, more than a century ago Bonwill and Gysi introduced the concept of balanced occlusion for dentures, in order to to provide the prostheses stability during mastication [41]. McLean transferred this concept to the natural dentition and advocated balanced occlusion for all dentitions. It was believed that the loss of alveolar bone during ageing could be prevented by balancing the occlusion [42]. Later on a shift was recommended from bilateral balanced occlusion towards unilateral balanced occlusion. The concept of unilateral balanced occlusion was developed by MacMillan on the basis of his personal observations of chewing movements of humans and animals [43].

In the unilateral occlusion concept, two working side schemes can be distinguished: canine protected occlusion (CPO) and unilateral group function occlusion. The advocates of CPO argued that humans innately possess the long and dominant canine that is evident in carnivorous animals. Canines are the strongest human teeth, and canines have the most sensitive proprioceptive fibers. In this view the canines are the best teeth to protect the occlusion from eccentric forces that occur on movements to and from centric occlusion. Studies on the prevalence of CPO also supported this assumption and a study showed that EMG activities in the masseter and anterior temporalis muscle could be reduced when splints with a steep canine rise were worn indicating a protective effect of canine guidance [41]. On the contrary the advocates of group function stated that canines are not necessarily the strongest teeth, and are not the last teeth to remain per se. Furthermore the canines do not necessarily have more sensitive proprioceptive systems than any other teeth [44]. The prevalence of group function is much larger than canine protected occlusion in other groups e.g. in Australian aborigines. Ramfjord and Ash not only believed in reduced EMG activities in patients wearing occlusal splints with a canine rise, but also argued that very prominent canines cause a too steep canine rise and also could obstruct normal lateral movements [41].

In the decades that followed, the concept of functionally generated path was introduced; anterior guidance and freedom in occlusion were the keys in this concept described by the Functional School. Both Functional and Gnathological Schools failed to describe all different patient characteristics, and merged into the concept of mutually protective occlusion [45,46]. In this concept a physiologic / healthy dentition is defined with the following keywords/ characteristics: *absence of pathology, sufficient function*, *adaptation* and *variability in form and function*. Fixed anatomical features are not prescribed. Opinions about canine guidance and group function applied to dentures and natural dentitions may sometimes be called dogma's, and they have proved to be very reluctant to alteration when new evidence is released [47].

There still remains uncertainty about the role of canine protected occlusion in terms of progression of tooth wear. Attritional wear on de the canines can be expected in canine guidance, it can be expected that these teeth will show more tooth wear than teeth without occlusal contact during excursions. There is no agreement about the assumed lower occlusal forces in cases of canine guidance compared to group function. Although increasing evidence is found for a central cause for bruxism rather than occlusion related causes, it is still believed that occlusal schemes play a role in the progression of tooth wear [48].

Canine Guidance

Canine protected occlusion (CPO) is a form of mutually protected articulation in which the vertical and horizontal overlap of the canine teeth disengage the posterior teeth during the excursive movements of the mandible [49]. During these excursive movements there will only be sliding contact on the cuspids of the working side (the side the mandible is moving towards), and both the posterior teeth the working and non-working side will lose occlusal contact. Subjects with CPO will have no tooth-tooth contact in the posterior area during lateral excursions and it is expected that those individuals show only minimal attritional tooth wear of (pre)molars. Concerning the canines, it is assumed that these teeth do not show negative wear results from this unilateral loading. The assumption is based on the favourable crown-root ratio, and the shape of the palatal surface, which is considered to be suitable to guide lateral excursions. It is also assumed that the chewing muscles will develop less force when only one tooth of the whole dentition has occlusal contact, instead of more teeth having simultaneously occlusal contacts [50].

The canines in CPO may wear and *canine protected occlusion* often transforms into *group function*. If that occurs there will also be occlusal contacts during excursive movements between the posterior teeth. When occlusal loading increases in the situation of group function, even more teeth may be affected by attrition. For this reason canine protected occlusion has been introduced as the 'appropriate' occlusion concept in restorative dentistry as to prevent tooth wear of teeth in the posterior area. Indeed, some studies indicate that most individuals with group function show more teeth with wear facets [23,51]. Other studies show different findings/results [52,53]. However the progression of wear in these studies is limited, as the total amount of tooth wear is now distributed over more teeth. It would therefore be interesting to study if canine protected occlusion could prevent or limit progression of attritional tooth wear.

The prevalence of CPO is not known. If its prevalence is high, a natural preventive mechanism may be incorporated in the human dentition. Based on epidemiological examinations it was concluded that there are differences in prevalence of CPO, based on differences in examined populations, cultures, food intakes, and the methods of the registration the occlusal contacts [54]. In the nineteen-sixties Scaife and Holt studied 1200 male students aged 17-25 years, and found 57% bilateral CPO, of which 14% presented faceting on teeth. In the group of individuals with group function, 53% presented faceting [51]. This finding is often referred to as evidence for the protecting aspect of canine guidance, although in the discussion part in the publication it was not stated to be proof a causal relationship. The question remains whether the formation of wear facets was allowed by the differentiation between the studied occlusion concepts, or was the occlusion concept a result of the presence of facets? The type of study that is expected to shed light on this dilemma is a longitudinal study design of the development of tooth wear rather than cross sectional studies.

Objectives

There is uncertainty about the prevalence of tooth wear, in both children and adults, and the causes and interactions of occlusion or occlusal factors on the one hand and tooth wear on the other. Therefore this thesis aims to investigate the prevalence of tooth wear, in adults and in children, and to find evidence in the literature describing interaction(s) between tooth wear and occlusal factors, function or dysfunction and threshold values for intervention. Furthermore the thesis aims to investigate the progression of tooth wear, investigating three aspects: the method to determine the type of dynamic occlusion, the method to measure tooth wear (quantitatively), a laboratory model to study artificial attrional tooth wear on curved and flat surfaces and the assessment of wear facets in a convenience sample of young adults. The present manuscript aims to confine to aspects concerning the research on tooth wear and its mechanism; the management or treatment options concerning tooth wear are not investigated or discussed.

Outline of the thesis

The first two chapters of this thesis consist of two literature reviews on prevalence studies. The prevalence of tooth wear in adults (Chapter 2) differ from the prevalence of tooth wear in children and adolescents (Chapter 3), therefore two different literature reviews on prevalence of tooth wear have been conducted. In Chapter 4, the third literature study investigates published papers on the relation between tooth wear and occlusion, (dys)function and intervention. The reviews include papers from 1980, up to the date of submission of the papers. Chapter 5 describes the influence of body position and occlusal contacts in lateral excursions, based on the finding that determining the type of occlusion on gypsum casts appeared to be less easy than assumed. Measurement of tooth wear is the subject of chapter 6; a simple method to assess tooth wear facets on gypsum models of young adults has been tested. The longitudinal measurement of tooth wear and occlusal factors in a convenient sample of young adults is presented in Chapter 7. A laboratory study to test what type of wear could be simulated with spherical and flat human enamel is described in Chapter 8. Chapter 9 discusses the findings of the 7 studies and addresses new evidence or questions that have risen since the research has been conducted.

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Prevalence of Tooth Wear in Adults

Van 't Spijker A, Rodriguez JM, Kreulen CM, Bronkhorst EM, Bartlett DW, Creugers NHJ, Prevalence of Tooth Wear in Adults. *Int J Prosthodont* 2009;22:35–42.

Abstract

Purpose: The aim of this study was to investigate data on the prevalence of tooth wear in adults and assess possible correlations using a systematic review.

Materials and Methods: A search of the literature, using PubMed and the Cochrane Library, from January 1980 to July 2007 was made using keywords “tooth + wear”; “dental + attrition + prevalence”; “dental + wear + prevalence”; “erosion + prevalence”; and “abrasion + prevalence.” References were independently screened for inclusion and exclusion by two investigators and Cohen’s Kappa was used as the measure of agreement. Data were collected and converted into the Smith and Knight Tooth Wear Index.

Results: One hundred eighty-six references were initially selected and subjected to the systematic review procedure; 13 survived the inclusion procedure. Four articles were suitable for regression analysis at tooth level ($R^2 = 0.593$) and three at subject level ($R^2 = 0.736$), using “age and age squared” and “age squared” as variables, respectively. Six studies reported males having significantly more tooth wear than females.

Conclusion: The predicted percentage of adults presenting with severe tooth wear increases from 3% at the age of 20 years to 17% at the age of 70 years. Increasing levels of tooth wear are significantly associated with age.

Introduction

There has been an increasing interest in tooth wear in dental literature. While there is a decline in the prevalence of caries in industrialized countries, some authors describe a general trend of increasing tooth wear, acid erosion in particular, amongst the young [1,2].

There are abundant data on the prevalence of tooth wear in children and adolescents, but data on adults are scattered. Anecdotal clinical experience suggests tooth wear in adults is common, but little evidence exists on the natural course of the condition. The irreversible and multifactorial aspects of wear of the teeth make it one of the most difficult dental problems to manage, and early diagnosis of pathological forms of wear is therefore important.

Many authors use the terms “tooth wear” and “erosion” interchangeably. Strictly, the definitions relate to different causes, tooth wear being recognized as the overarching term including erosion, abrasion, and attrition [3]. However, the emphasis by some researchers seems to target the term “erosion” rather than “abrasion” or “attrition.” Despite the terminology being widely accepted, the clinical appearance and interpretation of the types of tooth wear vary among clinicians [4].

Several indices used to describe the severity of tooth wear have been outlined in the literature. Indices grade tooth wear by recording surfaces, teeth, or the whole mouth [5–7]. One of the most commonly used indices was developed by Smith and Knight [7] and has been adapted by many researchers [8,9]. This index is easy to use and is not biased in the aetiology.

The prevalence of tooth wear in adults has been investigated by several studies, but clear data to describe general trends are lacking, partly because of the problems mentioned above. Based on the literature published since 1980, there is little evidence to suggest what the levels of tooth wear are in adults. The aim of this study was to investigate data on the prevalence of tooth wear in adults and assess possible correlations using a systematic review.

Material and Methods

Search, Inclusion, and Exclusion

Published literature from January 1980 to July 2007 was searched using PubMed and the Cochrane Library and different sets of keywords: *(1)* “tooth + wear”; *(2)* “dental + attrition + prevalence”; *(3)* “dental + wear + prevalence”; and *(4)* “(erosion + prevalence) and (abrasion + prevalence).” All titles and abstracts were read and any non-English publications, reviews, case reports, historical and forensic studies, in vitro and in situ studies (on nonhuman tooth material), and articles not describing prevalence were excluded. In the case of doubt or if an abstract was not available, the full article was examined. Articles that appeared to be the same, following the four separate search strategies, or separate articles from the same study were eliminated. Studies on subjects less than 18 years of age and on specific groups, such as alcoholics, were excluded.

References were independently screened for inclusion and exclusion by two investigators (NHJC and AVTS) and Cohen's Kappa (κ) was used as the measure of agreement. Disagreement was resolved after discussion and, when necessary, a third investigator (CMK) acted as the mediator. From the remaining references, the full-text articles were read. In addition, the reference lists of the included articles were hand searched using the same criteria. Appropriate references were cross-matched with the original list of references and those not already included were added.

Data Extraction

Papers were blinded of source information and only the sections "Materials and Methods" and "Results" (including tables and figures) were made available. The articles were jointly scrutinized by four investigators (NHJC, AVTS, DWB, and JMR) and data were extracted according to the headings shown in Tables 2.1 and 2.2. If the content of the data of a study was not clear to the investigators, the specific item was not recorded. Data from studies using indices other than the Smith and Knight [7] index were recalculated and if possible, converted to the Tooth Wear Index (TWI) (Table 2.2).

Statistics

Frequencies, percentage distributions, and age cohorts were recalculated or redefined if necessary. To quantify the relationship between the explanatory variables and the prevalence of tooth wear, linear regression models were used. These models estimate the change of the TWI corresponding to the change in a certain explanatory variable, for example gender or age. By including not only age but also "age squared" in these models, nonlinear relationships between age and the TWI could also be estimated. Preliminary analysis showed that regression was not possible for the variables "gender," "number of teeth," "tooth number," and "tooth surface," as there were insufficient data. Consequently, analysis was performed for "age" and the dependent variable "percentage of population presenting with tooth wear." According to Harrell, there is a limit to the number of variables in a model for regression analysis that is dependent on the number of data points [10]. Therefore, three regression models were tested: the first with only "age," the second "age and age squared", and the third only "age squared." The model with the highest adjusted R^2 was chosen (best fit). To correct for heteroscedasticity induced by differences in sample size at different ages, age groups were weighted with $\sqrt{N}$. Statistical analyses were done with SPSS 14.0.

Results

Search, Inclusion, and Exclusion

Figure 2.1 shows the number of references obtained by the four sets of keywords using PubMed. Inter-observer agreements were rated “moderate” to “very good” (κ ≥ 0.78). The Cochrane Library did not add any additional references. From a total of 1,953 references, 186 were initially selected based on the abstracts and titles. Of these, 90 were found in more than one search, leaving 96 separate papers, 74 of which were excluded because they targeted subjects less than 18 years of age or specific groups. From the 22 articles included for full-text assessment, 2 reported on the same population. The first [11] was on subjects older than 18 years, the second [12] up to 24 years. The latter did not provide additional data and was excluded. From the remaining 21 papers, 2 were thesis supplements [13,14] published in articles already included in the selection procedure and were excluded. An additional 6 studies were excluded, as the full-text article did not include data on prevalence [15–20]. Crosschecking the reference lists did not reveal any other articles.

The details and data from the remaining 13 studies [21–32] are summarized in Tables 2.1 and 2.2. Two, however, contained incomplete data [26,28]. The missing data were sourced from previously published work, allowing analysis to be completed [33,34].

Data Extraction

Eight studies reported wear on all tooth surfaces, one on the occlusal surface only, one on both the occlusal and cervical surfaces, and three on only cervical surfaces. One study reported only the data from erosion and another focused on anterior teeth (Table 2.1). Study populations were obtained from 10 countries. Seven studies were randomized population-based samples and six were convenient samples. The number of subjects was reported in all studies and the number of teeth reported in eight.

Six studies presented data at the subject level, five at the tooth level, and two on both (Table 2.2). The Smith and Knight [7] TWI was used in two studies and modifications of the index in six. One study [23] using this TWI converted data into pathological thresholds based on expected wear for different age groups and, since these data could not be compared to other studies, they were excluded from further analysis. Eight studies split the populations into age groups and presented wear as a mean for each group.

From the 13 papers it was only possible to compare wear on the occlusal and cervical surfaces. The overall percentages of extensive wear (TWI scores 3 and 4) at tooth level varied from 1.4% to 5.7% for occlusal and 3.9% to 24% for cervical wear. Subject level was reported by eight studies with a total of 4,593 subjects (range: 148 to 1,007 subjects per study). The seven studies reporting at the tooth level included 171,472 teeth in 9,476 subjects (range: 527 to 3,817 subjects per study). The most severely affected teeth were molars (three studies) [6,27,30] and the most commonly affected teeth were incisors (three studies) [6,21,30] and molars (one study) [27]. Six studies reported higher prevalence of tooth wear in males than females (Table 2.2). Two studies reported no significant difference and five did not analyse this variable.

Data Analysis

Subject Level: Three of the eight studies with data at the subject level described the percentage of the study population presenting with a TWI score of 3 or 4, of which two described the results at specific age cohorts (Figure 2.2). One study [6] could not be analysed because erosion was only recorded in subjects aged 26 to 30 and 46 to 50 years old. Two studies [25,29] used mean ages with a large range and could not be analysed further, except for the subjects up to 24 years old in the study by Rafeek *et al* [29]. Figure 2.2 shows that three studies were used to construct the regression model with age versus severe wear at levels 3 and 4. Hugoson *et al* [11] reported on occlusal surfaces but only those aged 20 to 50 years could be used for analysis. Salonen *et al* [22] and Rafeek *et al* [29] both reported on all surfaces. Regression analysis showed that the best fit was found in the model using “age squared” (Table 2.3).

Tooth Level: Four of the seven studies with data at tooth level described the percentage of teeth presenting with a TWI score of 3 or 4 and specified the age cohorts (Figure 2.3). The other three did not. Regression analysis showed that the best fit was found in the model using “age and age squared” (Table 2.3).

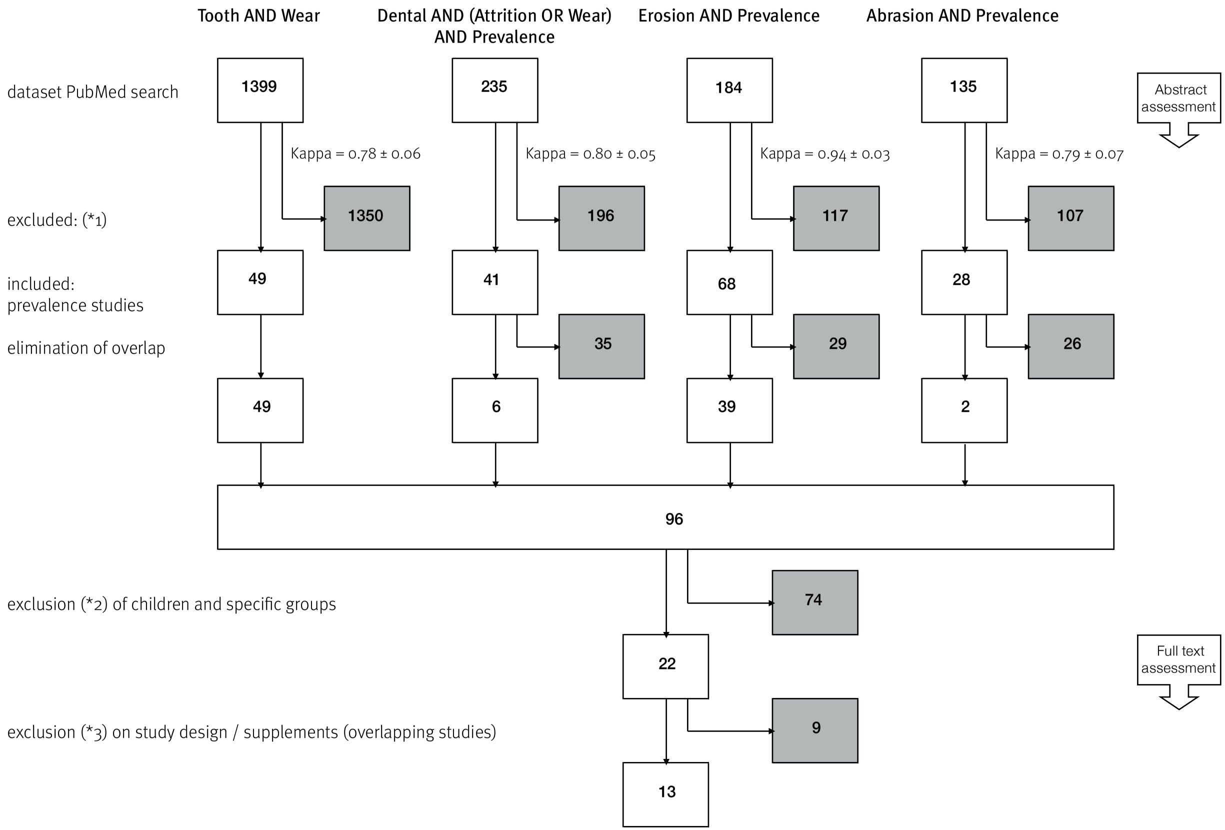

Figure 2.1 Flowchart describing the results of each step in the selection procedure.

Table 2.1 Sample Characteristics and Relevant Wear Measurement Specifications of the Included Studies

Reference	Country where study was done	Subject selection	No. of subjects (% female)		No. of teeth	No. of age groups (min. - max.)
Xhonga & Valdmanis, 1983 [29]	United States	UDC	527	(--)	16863	1 (14-88)
Hugoson et al., 1988 [11]	Sweden	RPB	585	(52)	13209	7 (20-80+)
Salonen et al., 1990 [21]	Sweden	RPB	751	(51)	--	7 (20-80+)
Lussi et al., 1991 [6]	Switzerland	RPB	391	(--)	--	2 (26-30, 46-50)
Donachie & Walls, 1995 [22]	United Kingdom	RPB	586	(--)	--	4 (45-75+)
Smith & Robb, 1996 [23]	United Kingdom	RDP	1007	(56)	--	6 (<25 to >65)
Milosovic & Lo, 1996 [24]	Malaysia (Borneo)	CS	148	(57)	3641	1 (14-77)
Nunn et al., 2000 [25]	United Kingdom	RPB	3817	(54)	45720*	1 (16-75)
Akgül et al., 2003 [30]	Turkey	UDC	428	(57)	--	4 (>20)
Borcic et al., 2004 [31]	Croatia	RDP	1002	(--)	18555	6 (10-65)
Taiwo et al., 2005 [26]	Nigeria	RPB	690	(42)	19280	1 (>65)
Bernhardt et al., 2006 [27]	Germany	RPB	2707	(53)	54204	8 (20-59)
Rafeek et al., 2006 [28]	Trinidad & Tobago	CS	155	(67)	1755	4 (16-65+)

TWI = Tooth Wear Index according to Smith & Night (1984)
-- No information / not described
RPB = Random Population Based
* Data found in reference and/or supportive paper
RDP = Random from Dental Practices
CS = Convenience sample
UDC = University Dental Clinic (patients)

			Reproducibility		
Surfaces assessed	Wear index used	No. of levels	Intra observer agreement	Inter observer agreement (no. of observers)	Remarks
Cervical	Depth of lesion	4	--	Not presented (2)	2 Clinics, 1 examiners each
Occlusal	Modified TWI	4	--	ICC 0,88 - 0,99 (7)	
All	Own classification	3	--	(1)	
All	Modified after Linkosalo & Markkanen (1985)	Facial: 4 Others: 3	--	κ= 0,80 - 1.00 (2)	Erosive lesions only
All	TWI	5	K = 0.84	(1)	
All	TWI	5	--	(1)	Subjects with ≥ 12 scorable teeth only
All	Modified TWI	4	κ= 0,63 - 0,78	(1)	
All	Modified TWI	4	--	κ= 0,44 - 0,96 * (75) *	Anterior teeth only
Cervical	Lesion present /not present	2	--	-- (--)	Buccally unrestored teeth only
Cervical	TWI cervical	5	--	(1)	
All	Modified after Eccles (1982)	4	--	71%	Elderly only
Occlusal Cervical	Modified TWI Cervical: yes /no lesion	4 2	κ= 0,68 - 0,91	κ= 0,53 - 0,74 (8)	Subjects with ≥ 4 teeth only
All	Modified TWI	4	--	-- (--)	

Table 2.2 Sample Characteristics and Relevant Wear Measurement Specifications of the Included Studies

Reference	Country where study was done	Subject selection	No. of subjects (% female)		No. of teeth	No. of age groups (min. - max.)
Xhonga & Valdmanis, 1983 29	United States	UDC	527	(--)	16863	1 (14-88)
Hugoson et al., 1988 11	Sweden	RPB	585	(52)	13209	7 (20-80+)
Salonen et al., 1990 21	Sweden	RPB	751	(51)	--	7 (20-80+)
Lussi et al., 1991 6	Switzerland	RPB	391	(--)	--	2 (26-30, 46-50)
Donachie & Walls, 1995 22	United Kingdom	RPB	586	(--)	--	4 (45-75+)
Smith & Robb, 1996 23	United Kingdom	RDP	1007	(56)	--	6 (‹25 to ›65)
Milosovic & Lo, 1996 24	Malaysia (Borneo)	CS	148	(57)	3641	1 (14-77)
Nunn et al., 2000 25	United Kingdom	RPB	3817	(54)	45720*	1 (16-75)
Akgül et al., 2003 30	Turkey	UDC	428	(57)	--	4 (›20)
Borcic et al., 2004 31	Croatia	RDP	1002	(--)	18555	6 (10-65)
Taiwo et al., 2005 26	Nigeria	RPB	690	(42)	19280	1 (›65)
Bernhardt et al., 2006 27	Germany	RPB	2707	(53)	54204	8 (20-59)
Rafeek et al., 2006 28	Trinidad & Tobago	CS	155	(67)	1755	4 (16-65+)

TWI = Tooth Wear Index according to Smith & Night (1984)
-- No information / not described
RPB = Random Population Based
* Data found in reference and/or supportive paper
RDP = Random from Dental Practices
CS = Convenience sample
UDC = University Dental Clinic (patients)

Surfaces assessed	Wear index used	No. of levels	Intra observer agreement	Inter observer agreement (no. of observers)	Remarks
Cervical	Depth of lesion	4	--	Not presented (2)	2 Clinics, 1 examiners each
Occlusal	Modified TWI	4	--	ICC 0,88 - 0,99 (7)	
All	Own classification	3	--	(1)	
All	Modified after Linkosalo & Markkanen (1985)	Facial: 4 Others: 3	--	κ= 0,80 - 1.00 (2)	Erosive lesions only
All	TWI	5	K = 0.84	(1)	
All	TWI	5	--	(1)	Subjects with ≥ 12 scorable teeth only
All	Modified TWI	4	κ= 0,63 - 0,78	(1)	
All	Modified TWI	4	--	κ= 0,44 - 0,96 * (75) *	Anterior teeth only
Cervical	Lesion present /not present	2	--	-- (--)	Buccally unrestored teeth only
Cervical	TWI cervical	5	--	(1)	
All	Modified after Eccles (1982)	4	--	71%	Elderly only
Occlusal Cervical	Modified TWI Cervical: yes /no lesion	4 2	κ= 0,68 - 0,91	κ= 0,53 - 0,74 (8)	Subjects with ≥ 4 teeth only
All	Modified TWI	4	--	-- (--)	

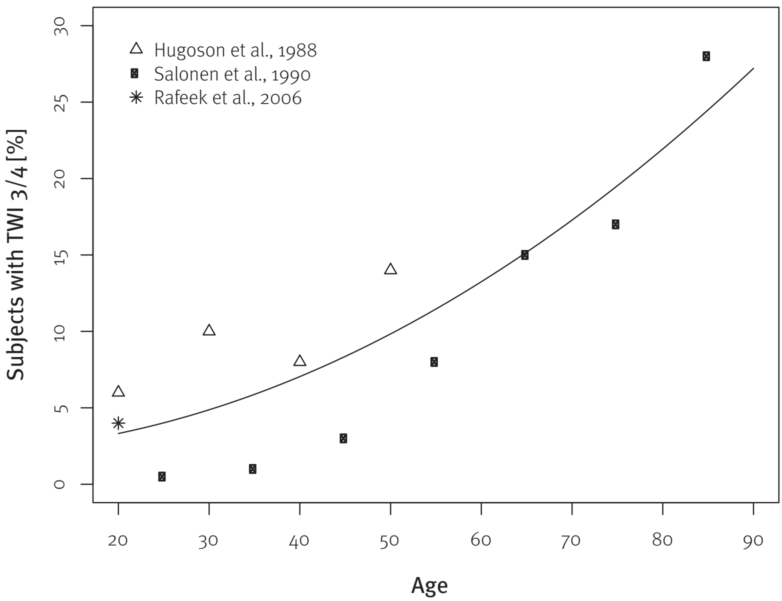

Figure 2.2 Regression model for subjects with a TWI score of 3 or 4.

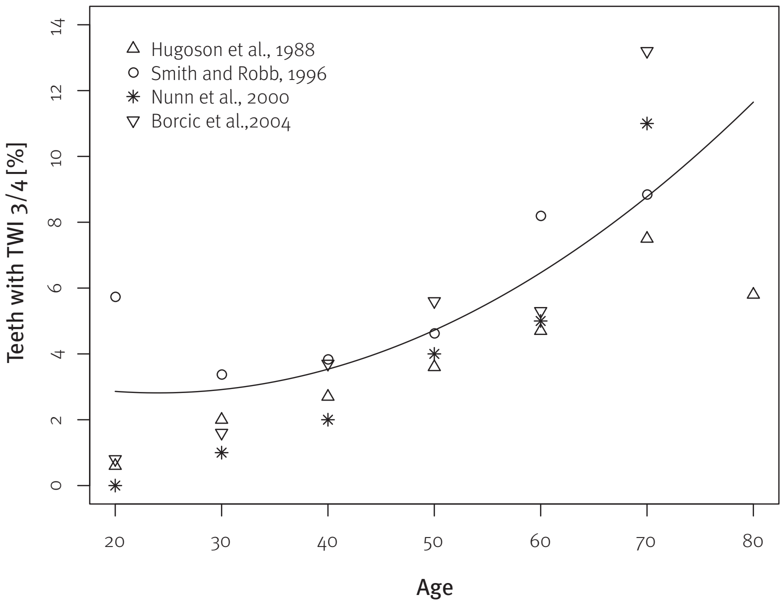

Figure 2.3 Regression model for teeth with a TWI score of 3 or 4.

Table 2.3 Parameters of the best fitting regression models for *subject* and *tooth* level analyses.

	Estimate	95% C.I.	P value
Subject level*			
Constant	2.08	[-1.80 ... 5.96]	.259
Age Squared	0.0031	[0.00179 ... 0.00441]	.001
Tooth level**			
Constant	4.44	[-0.956 ... 9.84]	.102
Age	-0.135	[-0.398 ... 0.127]	.297
Age squared	0.00281	[-0.000630 ... 0.00570]	.055

*Model significance: $P < .001$: $R^2 = 0.736$, **Model significance: $P < .001$: $R^2 = 0.593$

Discussion

We found relatively few studies on the prevalence of tooth wear conducted on adults, as most data report on children and adolescents. This probably reflects the difficulty of recruiting adults for representative samples on the prevalence of tooth wear. This is discouraging considering the increasing concern that both tooth wear and acid erosion cause clinicians. On the basis of the present data, it is realistic to state that tooth wear is common in adults, although it is not clear whether or not tooth wear is an increasing phenomenon. Longitudinal studies are needed to address this question.

Using too many keywords in electronic searches has the risk of introducing priori exclusion. For instance, a study by Bernhardt *et al* [28] described the prevalence of wear, but neither title, abstract, nor description of the purpose of the study mentioned the words “prevalence” and/or ”wear.” On the other hand, the studies by Nunn *et al* [26] and Bernhardt *et al* [28] prove that not all data can be found in the original articles and we were fortunate to have access to the missing data from complementary articles. We consider our protocols used to search the literature thorough and comprehensive. After applying the selection criteria, less than 1% of the references originally obtained from PubMed were included, which is in line with the experiences from other systematic reviews.

We explored prevalence studies and considered methodological aspects that might explain variation in results. However, strict guidelines for quality control of prevalence studies are lacking. We found that descriptions of sample constructions (external validity) did not allow any assessment of quality. In terms of internal validity, included studies were restricted to standardized measurements. However, there is no consensus on which index should be used to assess the severity of tooth wear. The Smith and Knight [7] index was the most common and straightforward for converting other indices. This paper supports the idea of adopting a widely held and used tooth wear index. It is unlikely that a single index will ever be fully adopted by all researchers, but it might be possible to use a skeleton index which can be adaptable to others, both in the collection and presentation of data. In the opinion of the authors and in line with our results, any overarching index must include an assessment of dentin exposure.

Some papers reported tooth wear on the tooth level and others on the subject level, which made comparison more challenging. In converting the original wear scores to TWI scores we dealt with subjective terms, such as "unacceptable level of wear," "severe wear," and "moderate wear." Converting these terms into TWI scores might have encountered some bias, which is why we used scores 3 and 4 as a sign of severe wear. Analysing lower levels of wear would have made the results more prone to bias due to the clinical difficulties in distinguishing worn from unworn surfaces. Also, higher levels of wear have more clinical relevance for clinicians restoring worn teeth.

There were differences in the studies included in the regression analysis, as they assessed different tooth surfaces. For example, Hugoson *et al* [11] reported data on occlusal surfaces whereas Salonen *et al* [22] and Rafeek *et al* [29] reported on all surfaces. The data from these two studies were combined for the analysis of age regression. Unfortunately, Hugoson *et al* [11] only provided data from the occlusal surfaces so it was not possible to tell what level of wear occurred on the other tooth surfaces. For the purposes of the regression analysis, the data from the three studies was sufficient to predict the relationship with age.

Most early tooth wear indices were developed in an attempt to match treatment need to severity and as such, are biased toward the more severe levels. The Smith and Knight [7] index has 5 levels, from 0 to 4, with wear on enamel denoted by level 1 and early dentin being exposed denoted by level 2. Therefore, the Smith and Knight [7] index is biased toward moderate (level 3) and severe (level 4) levels of tooth wear. The comparison of data between studies was possible at levels 3 and 4 but not possible at those that were less severe. This probably reflects the variability of the scoring system between the different modifications of the Smith and Knight [7] index. From a treatment perspective, the identification of levels 3 and 4 has more clinical significance than the less severe levels.

The difference in the final regression models underlines the importance in data presentation in terms of tooth and subject level. It is known that, apart from age and gender, diet and parafunctional behaviour have a role in the aetiology of tooth wear. While nearly half of the studies reported males to have significantly more tooth wear than females, not all studies reported on gender in a way that it could be used in the regression analysis, and even less so on diet or parafunctional behaviour. Therefore, regression analysis had to be limited to age.

The most interesting finding of this systematic review is that age and tooth wear are correlated to a significant level, with $R^2 = 0.736$ on the subject level and $R^2 = 0.593$ on the tooth level. The interpretation of these data suggests that tooth wear is a common clinical finding and will increase with age. The degree of association between age and tooth wear on subject level support the results that Milosevic and Lo [25] reported for a small sample ($\rho = 0.60$, $p = .001$).

Conclusion

The predicted percentage of adults presenting with severe tooth wear increases from 3% at age 20 years to 17% at age 70 years. Therefore, there is a tendency to develop more wear with age. It is not possible to state within the limited number of studies analysed whether this increase reflects greater severity of wear on the same tooth or greater number of teeth involved. To date, there are no longitudinal studies in adults or children that have measured wear progression on the same tooth. The Smith and Knight [7] index is a relatively crude index in that the changes at the tooth level increasing from index 2 to 3 or 3 to 4 represent a significant increase in the severity of tooth wear. For this reason, studies that have shown progression have done so by recording increased wear on all teeth rather than on progression on the same tooth [6].

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3

Systematic Review of the Prevalence of Tooth Wear in Children and Adolescents

Kreulen CM, Van ’t Spijker A, Rodriguez JM, Bronkhorst EM, Creugers NHJ, Bartlett DW.
Systematic Review of the Prevalence of Tooth Wear in Children and Adolescents.
Caries Res 2010;44:151–159.

Abstract

Data on the prevalence of tooth wear among children and adolescents are inconsistent. Given the impact of extensive tooth wear for over a lifetime, evidence on the extent is required. The aim was to systematically review the literature on the prevalence of tooth wear in children and adolescents.
A PubMed literature search (1980–2008) used the keywords 'tooth' AND 'wear'; 'dental' AND 'attrition' AND 'prevalence'; 'dental' AND 'wear' AND 'prevalence'; 'erosion AND prevalence' AND 'abrasion AND prevalence'. Following exclusion criteria, 29 papers were reviewed using established review methods. There was a total of 45,186 subjects (smallest study 80 and largest study 17,047 subjects) examined from thirteen multiple random clusters, eight multiple convenience clusters and eight convenience clusters. Nine different tooth wear indices were used, but the common denominator among studies was dentin exposure as an indicator of severe wear. Forest plots indicated substantial heterogeneity of the included studies.
Prevalence of wear involving dentin ranged from 0 to 82% for deciduous teeth in children up to 7 years; regression analysis showed age and wear to be significantly related. Most of the studies in the permanent dentition showed low dentin exposure, a few reported high prevalence (range 0–54%); age and wear were not related (regression analysis).
The results of this systematic review indicate that the prevalence of tooth wear leading to dentin exposure in deciduous teeth increases with age. Increase in wear of permanent teeth with age in adolescents up to 18 years old was not substantiated.

Introduction

Over the past 20 years, there have been a number of studies reporting the prevalence of tooth wear. A recent systematic review from our group on tooth wear in adults showed that prevalence of severe tooth wear increases with age [1]. A superficial inventory of data from studies in children and adolescents showed considerable variation in the level of dentin exposure from 0 to 53% of under 18-year-olds [2,3]. With such a marked difference and given the impact of extensive tooth wear for over a lifetime, an overview is desirable to establish its significance in the younger age groups.

The challenge in comparing data from different studies is to agree upon the outcome of the condition. Most prevalence studies use clinical tooth wear indices to measure wear on the surfaces of teeth as a coding system [4]. They differ considerably in their classification and definition of severity. Some indices measure tooth wear on every surface of every tooth [5], whereas others focus on index surfaces or teeth [6]. The consequence might be that researchers report different characteristics of the same phenomenon hampering a valid inventory. One area of consensus is the recognition of dentin exposure as an indicator for substantial loss of tooth tissue. It is a convenient cut-off, and if applied leads to a dichotomous wear scoring system. Nonetheless, exposure of dentin is a dramatic finding in permanent teeth at young age.

The aim of this research was to systematically review the literature on the prevalence of tooth wear in children and adolescents. By pooling data on the basis of the dichotomy of tooth wear, a meta-analysis was performed to relate wear scores to age, with a distinction between the deciduous (primary) and permanent (adult) dentition.

Materials and Methods

Search Strategy and Study Selection

The Cochrane Library revealed no systematic review on prevalence of tooth wear in children and adolescents up to 18 years old. Subsequently, we searched PubMed and Medline from January, 1980, to September, 2008, using the following combinations of keywords (1) 'tooth' AND 'wear'; (2) 'dental' AND 'attrition' AND 'prevalence'; (3) 'dental' AND 'wear' AND 'prevalence'; (4) 'erosion AND prevalence' AND 'abrasion AND prevalence'.

The four key word searches were limited to the medical subject headings and free text fragments. Trained reviewers independently screened titles and abstracts of the identified records for relevance (NHJC and AVTS.). The inclusion criteria for papers on tooth wear were the deciduous and permanent dentition using any clinical criteria without distinction of erosion, attrition and abrasion. Excluded were those not in English, reviews, case reports, historical and forensic studies, in vitro and in situ studies. In case of doubt and/or when an abstract was not available, the full-text copy of the article was examined. Inter-observer agreement was established (Cohen's kappa) and disagreement resolved after discussion. Where necessary a third reviewer (CMK) acted as a mediator and if unresolved the record was included. Duplicate references from the four separate search strategies were eliminated.

Full-text copies of the retrieved records were screened by the two observers using the same inclusion criteria extended by age to a maximum of 18 years. Studies on tooth wear prevalence in specific groups (e.g. Down syndrome) using a healthy control group were included since they could supply data, but those without controls were excluded. The five authors cross-checked bibliographies of the eligible papers for additional references. References not already included in the original list of records were reviewed by the 2 observers according to the protocol, and newfound studies were added.

Data Extraction

Eventually, selected papers were blinded to the source information and the 5 authors scrutinized their full-texts to retrieve data. Data were independently recorded onto a customized data extraction sheet and any disagreements resolved through discussion. Those studies not using a clinical tooth wear index, not indicating specific age groups, not reporting on wear related to specific age or not reporting wear on a subject level were excluded. We recorded general study characteristics and study quality parameters (Table 3.1). The frequencies and percentage distributions of tooth wear of deciduous and permanent teeth were recorded alongside the age group(s).

Data Synthesis and Analysis

Data from studies were transferred into enamel and dentin exposure. Score 0 was used for no wear or grades of enamel wear and score 1 for any wear into dentin ranging from minimal dentin exposure to pulp involvement; percentage distributions were recalculated accordingly. If age range but no mean age was reported, the middle age value was used. Heterogeneity was examined by plotting the proportions of score 1 against the year of publication of each study for the deciduous and the permanent dentition (forest plots). Meta-regression was performed with a fixed effect backward regression model to establish the relationship between prevalence of tooth wear and age. The dependent variable was the prevalence of dentin exposure and the independent variables were age and square root of age. By including these variables in the models, nonlinear relationships between age and prevalence could be estimated [1]. In the regression analyses, the observational unit was the reported prevalence for a specific age group. Reported prevalence was weighed by the square root of the study sample size. For studies with partial mouth recordings, the prevalence figure was upward adjusted using the following formula (*A* is the adjusted prevalence, *j* is the number of teeth measured):

$$A(j) = \frac{\sum_{i=1}^{j} 1 - 0.09 \times (i-1)}{\sum_{i=1}^{12} 1 - 0.09 \times (i-1)} \quad j = 1, \ldots, 12$$

Data on the significance of gender, socioeconomic status (SES), fluoridation, and diet for prevalence data were also analysed.

Results

Search and Study Selection

From a total of 2,230 identified records by the four search strategies, 204 were manually selected on the basis of their titles and abstracts, with inter-observer agreement of each search strategy rated as kappa ≥ 0.78. Eighty-nine records were duplicates. A further 65 were excluded as they reported on subjects older than 18 years or on specific groups without controls. Cross-referencing the remaining 50 papers revealed an additional 30 records of which 5 were included after applying the criteria, leaving 55 papers.

Data Obtained

Following full-text assessment of the 55 papers, 19 were excluded for a variety of reasons (nonclinical evaluation methods, wide age range of controls in prevalence studies amongst specific groups, no clear prevalence data reported or data at tooth level only). Of the remaining 36 papers, 11 were multiple publications of four data sets and the papers concerned were merged. The 29 studies representing the final body of evidence are shown in Table 3.1. Most studies were conducted in the UK (13) and the remainder ranged across the continents. One study was performed in both the UK and the USA. The ages ranged between 1.5 and 18 years. Most studies reported that equal proportions of boys and girls were included. Five studies did not report this item. Fifteen studies reported a single age group, 7 included two up to four age groups, 3 included five or more age groups and 4 studies merged subjects with an age range into one group. Fourteen studies included subjects younger than 7 years, studying the deciduous dentition. Eighteen studies included subjects older than 6 years; 5 studies included the mixed dentition and 4 of those were among the 18 studying the permanent dentition. In the mixed dentition, the permanent teeth were subject of observation. The number of teeth examined varied between studies. Twelve studies reported wear on all teeth and 17 on specific teeth with the maxillary incisors being the most common. In 12 studies, registration was limited to palatal and buccal surfaces, in 16 studies the occlusal surfaces of molars were additionally registered.

Table 3.1 Characteristics of the included studies

	Reference	Year	Country	Design	Nr. of clusters	Nr. of subjects	Perc. female	Nr. of age groups	Age per group or age range (yrs)	Type of dentition (D, M, P)	Surfaces analysed (P, B, I, O, C)
1	Al-Dlaigan et al.	2001a	United Kingdom	MRC	12	418	50	1	14	P	P + B
		2001b									
		2001c									
2	Al-Malik et al.	2001a	Saudi Arabia	MRC	17	987	48	3	3, 4, 5	D	P + B
		2001b									
		2002									
3	Al-Malik et al.	2000	Saudi Arabia	C	1	80	36	2	4, 5	D	P + B
4	Auad et al.	2007	Brazil	MCC	14	458	59	1	14	P	P + B
											O
5	Ayers et al.	2002	New Zealand	MRC	not reported	104	51		5 thru 8	D	P + B + I + O
6	Bardsley et al.	2004	United Kingdom	MRC	55	2385	52	1	14	P	P + B + I
	Milosevic et al.	2004									O
7	Bartlett et al.	1998	United Kingdom	C	1	210	51		11 thru 14	P	P + B + I + O + C
8	Chadwick et al.	2006	United Kingdom	MRC	689	10381	not reported	4	5, 8, 12, 15	D, M, P	P + B
											O
9	Deery et al.	2000	United Kingdom and United States	C	3	254	57		11 thru 13	P	P + B
10	Deshpande and Hugar	2004	India	C	1	100	40	1	5	D	P + B + I + O
11	De Carvalho et al.	2008	Brazil	MCC	8	295	52	1	12	P	P + B + I + O
12	Dugmore and Rock	2003a	United Kingdom	MRC	62	1753	48	1	12	P	P + B
		2003b									
		2004									P + B + O
13	El Aidi et al.	2008	Netherlands	C	1	622	49	1	13	P	P + B + O
14	El Karim et al.	2007	Sudan	MCC	4	157	57	1	13	P	P + B

Teeth observed	Wear index (modification)	Nr. of obervers	Training	Inter observer agreement (Kappa)	Intra observer agreement (Kappa)	Effect gender (sign. level)	Effect diet (sign. level)	Content SES	Effect SES (siggn. level)	Effect water F (sign. level)
All teeth	Mod TWI (Millward)	1	Yes	0.80	0.91	Males > Females (P< 0.001)	Yes (P<0.05)	postcode	Low > High (P< 0.001)	not studied
Max. incisors	Mod TWI (Al-Malik)	1	Yes	not reported	0.92	not reported	Yes (P<0.001)	occupation / education parents	No (P>0.05)	not studied
Max. incisors	Mod TWI (Al-Malik)	1	Yes	not reported	0.92	not reported	not studied		not studied	not studied
Max. incisors	Mod TWI (O'Brien)	1	Yes	0.75	0.83	No (P>0.05)	not studied	economical status	No (P>0.05)	not studied
4 first molars										
Canines + prim. molars	Mod TWI (Millward)	1	not reported	not reported	not reported	No (P>0.05)	No (P>0.05)		not studied	not studied
All anteriors	Mod TWI (Bardsley)	1	Yes	0.70	0.6 - 0.8	Males > Females (P< 0.001)	Yes (OR>1)	postcode	High > Low (P<0.001)	Protective (P<0.001)
4 first molars										
All teeth	TWI	1	Yes	not reported	0.96	No (P>0.05)	No (P>0.05)		not studied	not studied
Max. incisors	Mod TWI (O'Brien)	66	Yes	not reported	not reported	not reported	not studied		not studied	not studied
4 first molars										
Max. incisors	Mod TWI (O'Brien)	2	Yes	0.39 and 0.61	0.58 and 0.62	No (P>0.05)	No (sign. level not reported)		not studied	not feasible
All teeth	Mod TWI (Nunn)	2	No	not reported	not reported	not reported	not studied		not studied	not studied
All teeth	Mod TWI (Al-Malik)	2	Yes	0.80	0.85	No (P>0.05)	not studied		not studied	not studied
All incisors	Mod TWI (O'Brien)	1	Yes	not reported	0.80	Males > Females (P< 0.01)	not studied	postcode	Low > High (P<0.05)	not studied
4 first molars										
All teeth	Mod Lussi (Rijkom)	2	Yes	0.65	not reported	Males > Females (P<0.05)	not studied	postcode	Low > High (P<0.05)	not studied
Max. incisors	Mod TWI (O'Brien)	1	Yes	not reported	0.80	not reported	Yes (P<0.01)	school social status	High > Low (P<0.001)	not studied

Table 3.1 Characteristics of the included studies *(Continued)*

	Reference	Year	Country	Design	Nr. of clusters	Nr. of subjects	Perc. female	Nr. of age groups	Age per group or age range (yrs)	Type of dentition (D, M, P)	Surfaces analysed (P, B, I, O, C)
15	Harding et al.	2003	Ireland	MCC	18	202	48	1	5	D	P + B
16	Hinds and Gregory	1995	United Kingdom	MRC	not reported	1496	49	3	2, 3, 4	D	P + B
17	Jones and Nunn	1995	United Kingdom	MRC	7	135	48	1	3	D	P + B
18	Larsen et al.	2005	Denmark	MCC	4	558	48		15 thru 17	P	P + B + I + O
19	Luo et al.	2005	China	MRC	10	1949	47	3	3, 4, 5	D	P + B
20	Millward et al.	1994a	United Kingdom	MCC	5	178	55	1	4	D	P + B + O
21	Milosevic et al.	1994	United Kingdom	MRC	10	1035	49	1	14	P	P + B + I + O + C
22	O'Brien	1994	United Kingdom	MRC	1556	17061	not reported	11	5 thru 15	D, M, P	P + B
23	Ogunyinka et al.	2001	Nigeria	C	1	176	62	7	12 thru 18	P	P + B + I + O
24	Peres et al.	2005	Brazil	C	1	391	48	1	12	P	P + B + I
25	Van Rijkom et al.	2002	Netherlands	MRC	13	745	54	2	12, 16	M, P	P + B + I + O
26	Walker et al.	2000	United Kingdom	MRC	132	1726	not reported	4	4 thru 18	D, M, P	P + B O
27	Wiegand et al.	2006	Germany	MCC	21	463	47	6	2 thru 7	D, M	P + B + I + O
28	Williams et al.	1999	United Kingdom	MCC	12	525	not reported	1	14	P	P + B

D Deciduous
M Mixed
P Permanent
P Palatal
B Buccal
I Incisal
O Occlusal
C Cervical
SES Social Economical Status
MRC Multiple Random Cluster
MCC Multiple Convenience Sample
C Convenience

Teeth observed	Wear index (modification)	Nr. of obervers	Training	Inter observer agreement (Kappa)	Intra observer agreement (Kappa)	Effect gender (sign. level)	Effect diet (sign. level)	Content SES	Effect SES (siggn. level)	Effect water F (sign. level)
Max. incisors	Mod TWI (Al-Malik)	1	Yes	0.80	0.90	not reported	Yes (P<0.05)	economical status	Low > High (P<0.05)	No (P>0.05)
Max. incisors	Mod TWI (O'Brien)	not reported	Yes	not reported	not reported	not reported	not studied	occupation / education parents	not reported	not studied
Max. incisors	Mod TWI (O'Brien)	1	Yes	not reported	0.86	not reported	not studied	postcode	Low > High (sign. level not reported)	not studied
All teeth	Mod TWI (Eccles + Lussi)	9	Yes	not reported	not reported	Males > Females (OR=2.6)	not studied		not studied	not studied
Max. incisors	Mod TWI (Al-Malik)	3	Yes	0.86 - 0.88	not reported	No (P>0.05)	Yes (P<0.05)	education parents	High > Low (P<0.05)	not studied
All teeth	Mod TWI (Millward)	1	Yes	not reported	0.93	not reported	not studied	social status	High > Low (P=0.05)	not studied
All teeth	TWI	1	Yes	not reported	0.85	Males > Females (P< 0.01)	not studied	social status	Low > High (P<0.05)	not studied
Max. incisors	Mod TWI (O'Brien)	76	Yes	SDPU 0-0.12	not reported	not reported	not studied	social status	not reported	not studied
All teeth	Mod TWI (O'Brien)	1	not reported	not reported	0.83	No (P>0.05)	not studied		not studied	not studied
Max. incisors	O'Sullivan	1	Yes	not reported	0.78	No (P>0.05)	not studied	school social status	High > Low (P<0.01)	not studied
All teeth	Mod Lussi (Rijkom)	2	Yes	0.47	not reported	Males > Females (P< 0.001)	No (P>0.05)	postcode	High > Low (P<0.05)	not studied
Max. incisors 4 first molars	Mod TWI (O'Brien)	65	Yes	-0.12 - 1.00	not reported	No (P>0.05)	No (P>0.05)	postcode	Low > High (OR > 2)	not studied
All teeth	O'Sullivan	1	Yes	not reported	not reported	Males > Females (sign. level not reported)	No (P>0.05)		not studied	not studied
Max. incisors	Mod TWI (O'Brien)	1	Yes	not reported	>0.80	not reported	No (P>0.05)		not studied	not studied

Max. Maxillary
Prim. Primary
TWI Tooth Wear Index (Smith & Knight 1984)
Mod. Modified
OR Odds Ratio
SDPU Standard deviation per unit measured

There was a total of 45,186 subjects (smallest study 80 subjects, largest study 17,047 subjects) examined from thirteen multiple random clusters, eight multiple convenience clusters and eight convenience clusters. Nine different tooth wear indices were used. The Tooth Wear Index (TWI) by Smith and Knight [5] and five modifications were used in 24 studies, of which one index [3] was specifically directed to dentin wear. Five studies used scoring systems unrelated to the TWI. The majority of studies used a single, trained observer to a maximum of 76 observers. Twenty-five studies trained examiners, and the range for inter- and intra-examiner reproducibility was −0.12 to 1.00 and 0.58 to 0.96 respectively, or were not reported in 18 and 11 studies, respectively (Table 3.1).

Data Synthesis

All tooth wear data were dichotomized; prevalence of wear involving dentin ranged from 0 to 82% in deciduous teeth of children up to 6.5 years (13 studies) and from 0 to 54% in permanent teeth of children 7 years and older (18 studies). The forest plots indicate a substantial heterogeneity of studies in terms of prevalence outcome (Figure 3.1). Four studies were excluded since prevalence was not related to age or data were inconclusive regarding prevalence related to tooth or subject level [7-10]. Figure 3.2 shows the scatter plots of prevalence of dentin exposure to age for the deciduous and permanent teeth. Results of the regression analyses for the deciduous dentition, based on 19 observations (ages 2–6 years, overall n = 11,639), are shown in Table 3.2. The regression models for the reported and the adjusted prevalence were significant, with age as the explanatory variable, but estimates were similar. For permanent teeth the regression models, based on 31 observations (ages 7 to 16.5 years, overall n = 32,408), were not statistically significant (Table 3.2).

Further Analyses

Seventeen studies reported the relationship between tooth wear and gender. Eight found significantly more tooth wear with males compared to females, while 9 studies reported no difference. Impact on SES was reported in 15 studies using criteria such as postcode, occupation of parents and economic status. Of these, 6 showed subjects with higher SES had more tooth wear, 7 reported the reverse and 2 no relationship. Of the 3 studies that reported on water fluoridation, one reported a significant protective effect on tooth wear, one no effect and one study could not obtain reliable data. The relationship between diet and tooth wear was investigated in 14 studies with 6 reporting statistically significant relationships and 8 reporting no relationship. The content of the variable diet was obscure and any conclusion is not allowed on the basis of the present data. Statistical analysis of the four variables above was not feasible with these data.

Table 3.2 Parameters of the fit of the regression models.

	Estimate	95% CI	P value
Deciduous teeth			
Reported prevalence			
R^2	0.287		.016
Constant	-9.853	[-29.655 ... 9.949]	.309
Age	5.482	[1.169 ... 9.795]	.016
√Age	Not in the model, F >= .100		
Adjusted prevalence			
R^2	0.329		.009
Constant	-12.190	[-34.181 ... 11.518]	.259
Age	6.729	[1.939 ... 11.518	.009
√Age	Not in the model, F >= .100		
Permanent teeth			
Reported prevalence			
R^2	0.092		.097
Constant	-32.849	[-80.335 ... 14.638]	.168
Age	11.471	[-2.195 ... 15.136]	.097
√Age	Not in the model, F >= .100		
Adjusted prevalence			
R^2	0.095		.091
Constant	-33.539	[-81.335 ... 14.289]	.162
Age	11.762	[-2.001 ... 25.525]	.091
√Age	Not in the model, F >= .100		

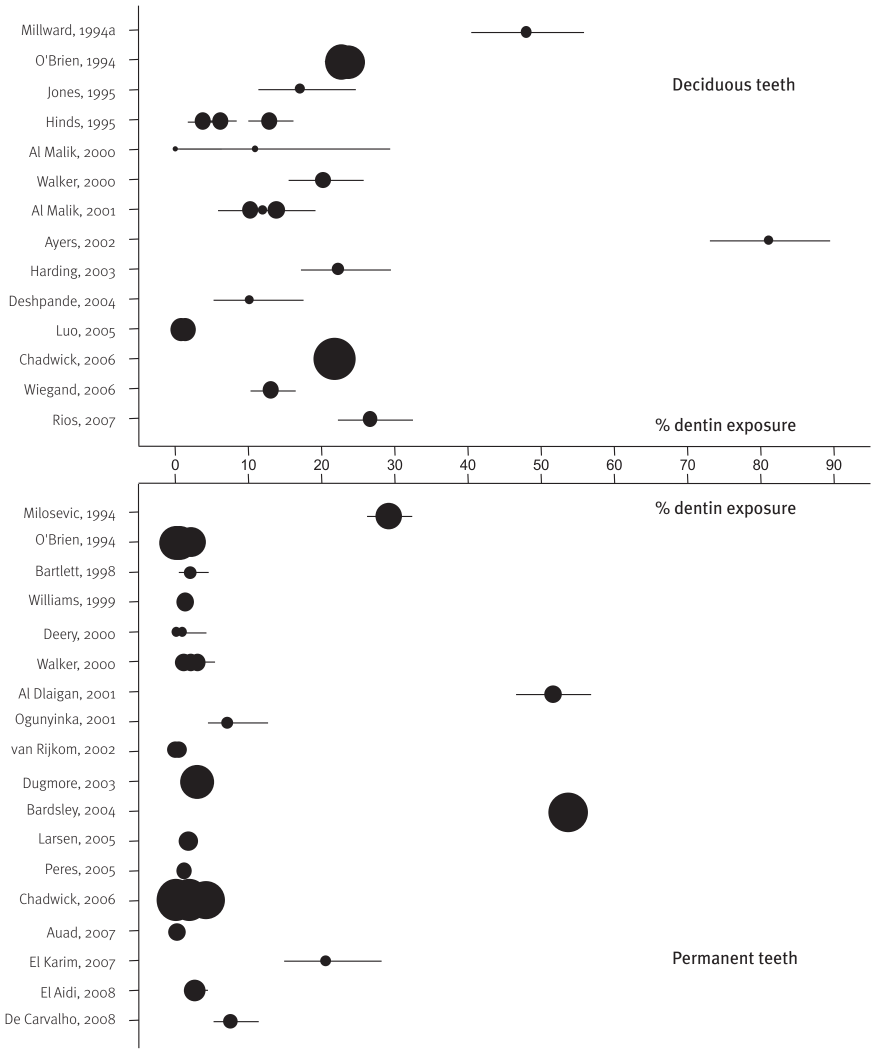

Figure 3.1 Forest plots showing prevalence of dentin exposure per study.

Because more than one age group, with the accompanying prevalence figures, can be involved in a study, the equivalent number of data points is shown on the graph. Studies are ordered by year of publication. The upper forest plot represents studies observing the deciduous dentition, the lower plot the permanent dentition. The area of the circles reflects the size of the study based on the square root of N. The horizontal line corresponds to the recalculated 95% confidence interval of each data point.

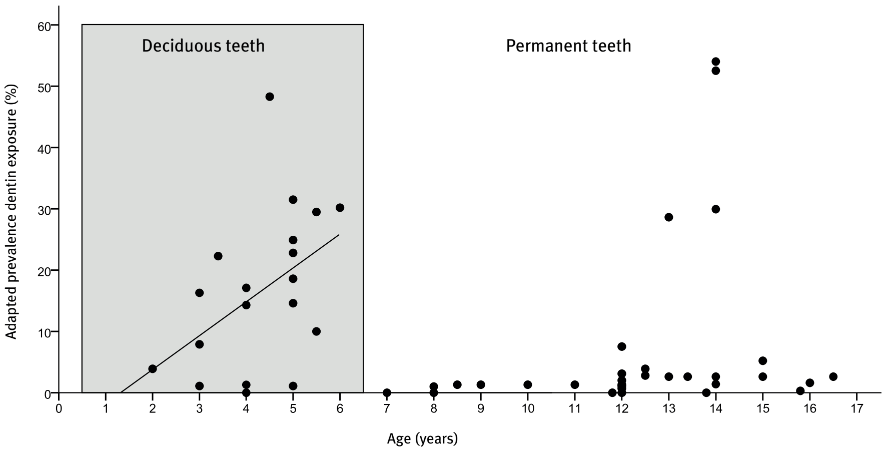

Figure 3.2 Scatter plot of the adjusted prevalence of dentin exposure related to age as found in the included studies.

Regarding the non-significant regression model, it was not possible to construct a reliable regression line for the permanent dentition of children and adolescents under 18 years of age.

Discussion

The results of this systematic review indicate that the prevalence of tooth wear into the dentin of deciduous teeth in children increases linearly with age. The significant relationship of extensive tooth wear to age in the deciduous dentition, but not in the permanent dentition, suggests that the deciduous teeth are less wear resistant than permanent teeth, which confirms laboratory findings [11]. Considering the duration of exposure of permanent teeth in adolescents, any relationship to wear would have been a surprising outcome. The combination of the time of exposure and the resistance of teeth to wear seems to be dependent on age. A few studies reported high prevalence, but most of the studies in the permanent dentition showed low dentin exposure. In the deciduous dentition, the majority of studies showed higher levels of dentin exposure.

Despite the large number of subjects included (more than 32,000), no definite conclusions could be drawn regarding increase in wear with age for the permanent dentition of children and adolescents. The variation in prevalence of wear prevented the construction of adequate regression models. Differences in the design of the included studies may be the source of the variance in outcomes, and the impact of different methodologies prevented weighing outcomes on the basis of study quality parameters [12]. The main methodological difference between studies was the tooth wear index used. Nine more or less distinct tooth wear indices were applied in 29 studies, but the common denominator was dentin exposure. Comparative analysis of wear at this level was the most appropriate way to analyse the data, although recent research suggests that visible determination of dentin exposure from differences in colour between enamel and dentin is not invariably specific [13]. There is also no international consensus of how to grade the presence or severity of tooth wear, while the present data reflect a wide observer agreement variation of indices. As most researchers reported dentin exposure, it should be used as the minimum threshold for future research.

Some studies used a partial mouth recording, and others recorded all teeth of the dentition. The number of registered surfaces per tooth also varied, and variation in these numbers had a consequence on the prevalence. Recording higher numbers of surfaces at risk may increase the chance of finding just one surface with wear score 1 within the subject. Per study, the prevalence was adjusted for the number of observed teeth by post hoc analyses, but regression models were not improved. The assumption with these adjustments was that each tooth had the same risk of dentin exposure. However, it is reported that deciduous canines exhibit the most prevalent and severe wear [14]. Indeed, 3 out of 4 studies from our systematic review that included canines in their observations reported 25% and higher prevalence of dentin exposure in the deciduous dentition [8,10,15]. All other studies reported below 24% prevalence, which indicates that focusing on incisors might lead to an underestimation of the prevalence of severe wear.

The variation in the indices prevented a detailed grading of wear, specifically those on enamel. Definitive conclusions on enamel wear would be ideal particularly for the consequences of prevention at a population level. The prevalence of dentin exposure in the permanent dentition of adolescents suggests that at some level tooth wear is an important consideration for dental health. Unlike periodontal disease or caries, tooth wear remains a relatively new concern. We cannot identify a specific factor influencing the prevalence of wear in these young age groups, neither can we affirm the role of (changing) diet in the development of severe wear on the basis of the present data. Any differences between countries could not validly be traced. There has been a tendency to consider the concept of pathological levels of tooth wear, but in absence of consensus, the differentiation between what is pathological and what physiological remains a subjective and individual judgment. Yet, the present systematic review could not substantiate the suggested increase in extensive tooth wear of permanent teeth with age in subjects up to 18 years old. Regarding deciduous teeth in children up to 7 years old, the results indicate that the prevalence of tooth wear into the dentin increases significantly with age.

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4

Attrition, occlusion, (dys)function, and intervention: a systematic review

Van 't Spijker A, Kreulen CM, Creugers NHJ. **Attrition, occlusion, (dys)function, and intervention: a systematic review.** *Clinical Oral Implants Research* 2007;18(Suppl 3): 117-26.

Abstract

Objectives: Attrition and occlusal factors and masticatory function or dysfunction are thought to be related. This study aims to systematically review the literature on this topic with the emphasis to find evidence for occlusion-based treatment protocols for attrition.

Materials and methods: Literature was searched using PubMed (1980 to 2/2006) and the Cochrane Library of Clinical Trials with the keywords 'tooth' and 'wear'. Five steps were followed. Exclusion was based on the following: (1) reviews, case-reports, studies on non-human tooth material, and studies not published in English and (2) historical or forensic studies. Included were (3) in vivo studies. Next, studies on (4) occlusal factors, function or dysfunction [temporomandibular disorders (TMD), bruxism], or intervention, and (5) attrition were included. Two investigators independently assessed the abstracts; measure of agreement was calculated using Cohen's κ; disagreement was resolved by discussion. Full-text articles were obtained and correlation between outcomes on occlusal factors, (dys)function, treatment, and attrition were retrieved. References in the papers included in the final analysis were cross-matched with the original list of references to add references that met the inclusion criteria.

Results: The search procedure revealed 1289 references on tooth wear. The numbers of included studies after each step were (1) 345 (κ = 0.8), (2) 287 (κ = 0.87), (3) 174 (κ = 0.99), (4) 81 (κ = 0.71), and (5) 27 (κ = 0.68). Hand searches through the reference lists revealed six additional papers to be included. Analysis of the 33 included papers failed to find sound evidence for recommending a certain occlusion-based treatment protocol above another in the management of attrition.

Conclusion: Some studies reported correlations between attrition and anterior spatial relationships. No studies were found suggesting that absent posterior support necessarily leads to increased attrition, though one study found that fewer number of teeth resulted in higher tooth wear index (on the remaining teeth). Attrition seems to be co-existent with self-reported bruxism. Reports on attrition and TMD signs and symptoms provide little understanding of the relationship between the two.

Introduction

Extensive tooth wear is considered a potential threat to functional dentition. The management of tooth wear, especially from attrition, is becoming a subject of increasing interest in the prosthodontic literature, both from a preventive [how to stop the progress of tooth substance loss (TSL)] and from a restorative point of view (how to replace the lost tooth substance and to restore function).

By definition, attritional wear is the loss of tooth tissue due to friction between opposing teeth and is thus related to dental occlusion. In a classical paper on attrition, Berry & Poole [1] considered TSL to be a normal ageing process, in which depositioning of secondary dentine, alveolar growth, muscle adaptation, and attrition are all part of a compensation mechanism. They stated that 'if this concept is right, then attrition, whatever its extent, can never be excessive' (Berry & Poole 1976). However, loss of tooth tissue usually affects the dental occlusion and it is still disputed whether a changing occlusion could be ignored in the management of dental problems such as 'extensive' attrition or temporomandibular disorders (TMD).

The role of occlusion as a key factor in the treatment of mutilated dentitions is less disputed. Although almost completely empiric-based, occlusal concepts are willingly used in both conservative dentistry and prosthodontics to compass the restorative process of broken down or worn teeth and dentitions. The scientific evidence of the use of occlusal concepts and the knowledge regarding the role of occlusal factors in (the management of) tooth wear is fragmented and ambiguous, as is the relationship between (management of) tooth wear and (dys)function.

In the management of tooth wear, the prosthodontist has to make decisions regarding the need for treatment, treatment procedures, materials' choice, and occlusal concepts. With regard to treatment need it has been advised that tooth wear should be diagnosed early and treated timely 'to prevent the tooth from wear beyond a point of acceptable restoration' [2]. In contrast, careful monitoring has been advised above early treatment because the progress of tooth wear might fluctuate [3,4]. Regarding treatment procedures and materials' choice, a wide variation of options has been proposed in the dental literature, most of it in textbooks, case reports, or clinically oriented reviews. Besides the traditional prosthodontic restorations used in oral rehabilitation, direct and indirect composite restorations [5,6], bonded cast metal restorations [7,8], implant-supported removable partial dentures [9], orthodontic treatment [10], and (protective) splints [11] have been proposed. Yet, no evidence is available for choosing one of these treatment options above another.

The purpose of the present study was to systematically assess relationships, if any, between attrition and occlusal factors and oral (dys)function in terms of management of attrition. More specifically, the aims were (1) to find and assess evidence from the literature for patients with attrition and TMD regarding choice of intervention, (2) to map evidence addressing occlusion-based protocols and occlusal factors in the management of attrition, and (3) to find evidence for defining a certain threshold, at which interventions are indicated in subjects with attrition.

The null-hypothesis was the literature provides no sound evidence justifying the qualification of certain occlusion-based interventions above others in the management of attrition.

Material and methods

This systematic review is characterized by four major elements: literature search, inclusion/exclusion of papers, extraction and grouping of study outcomes, and outcome analysis.

Literature search

The literature was searched using PubMed with limitation of publication year from 1980 up to February 2006 as well as the Cochrane Library of Clinical Trials. Key words used in the literature search were: 'tooth' in combination with 'wear'.

Inclusion/exclusion of papers

From this dataset, references were selected with 'wear of human tooth tissue' as the study subject. Two independent readers (AVTS and NHJC) selected references to be included on the basis of abstracts. The search was not limited to randomized controlled trials (RCTs). Excluded were reviews, case reports, comments, and references in which wear other had meanings than loss of tooth tissue. References to non-English articles were also excluded. If abstracts were not available in PubMed, original published articles were obtained. Observer agreement was analysed and disagreements were resolved by discussion.

Second, references that were identified as 'historical studies or forensic' were excluded. A reference was considered 'historical' if the material studied was a non-living human material (e.g., skulls). In a third step, references to in vivo studies were included while in vitro and in situ studies were excluded. The fourth step emphasized on including studies that investigated relationships of tooth wear with either (1) occlusal factors (including 'occlusal designs for oral reconstruction'), (2) function or dysfunction (TMD, bruxism), and (3) intervention or dental treatment history. Also, studies investigating indication thresholds for restorative vs. non-restorative intervention were included. In the fifth step, only studies providing outcome data on attrition were included to the final dataset. References in the papers included in the final analysis were cross-matched with the original list, adding further references that met the inclusion criteria. Observer agreement was analysed for each step and again disagreements were resolved by discussion.

Grouping and extraction of study outcomes

From the papers that resulted after step 5, full-text versions were obtained and read. The reviewers classified the papers independently according to the different study topics in four categories: (1) occlusal parameters, (2) functional parameters (including TMD or bruxism), (3) intervention or treatment history, and (4) threshold values for treatment of attrition. Information regarding study design, research questions, populations under investigation, measurement methods, and study outcomes were extracted. Final classification was based on consensus between reviewers and in case of disagreement a third reviewer (CMK) was the mediator.

Assessment of study outcomes and statistical analysis

For all steps, Cohen's κ coefficient was used as a measure of agreement between the two reviewers. Study outcomes were to be pooled, but only a qualitative assessment was achievable. Correlations between parameters and outcome (attrition) were retrieved.

Results

The PubMed search resulted in a list of 1289 references. A total of 345 references were entered in the tooth wear dataset containing studies addressing wear of human tooth tissue. Search of the Cochrane Library of Clinical Trials did not reveal further relevant papers. The complete selection procedure resulted in the inclusion of 27 articles (Figure 4.1). Observer agreements (κ) ranged from 0.68 ± 0.08 (fair) to 0.99 ± 0.01 (very good). Hand search through the reference lists revealed six additional papers to be included, all of them dealing with functional parameters and attrition [12-17]. Finally, 11 articles reporting data on attrition and occlusal parameters, 21 articles with data on attrition and functional parameters, and four articles evaluating intervention or treatment effects were subjected to further analysis. Three studies [16,18,19] dealt with both occlusal and functional parameters and were therefore included in both sub-sets. Another two studies [20,21] addressed research questions related to occlusal parameters in dental situations resulting from active dental treatments. For practical reasons, these studies were allocated to the occlusal parameters group only. No papers were identified investigating threshold values of TSL, at which interventions are indicated in subjects with attrition.

The studies selected for the category occlusal parameters showed large heterogeneity in study design, sample composition, research question, and measurement method (Table 4.1). As a result, pooling of outcome data was not possible. Only few correlations between attrition and occlusal parameters were reported. No correlation between anterior attrition and absent posterior teeth was reported; only some statistical correlations were found for specific sub-samples [4,21]. However, differences

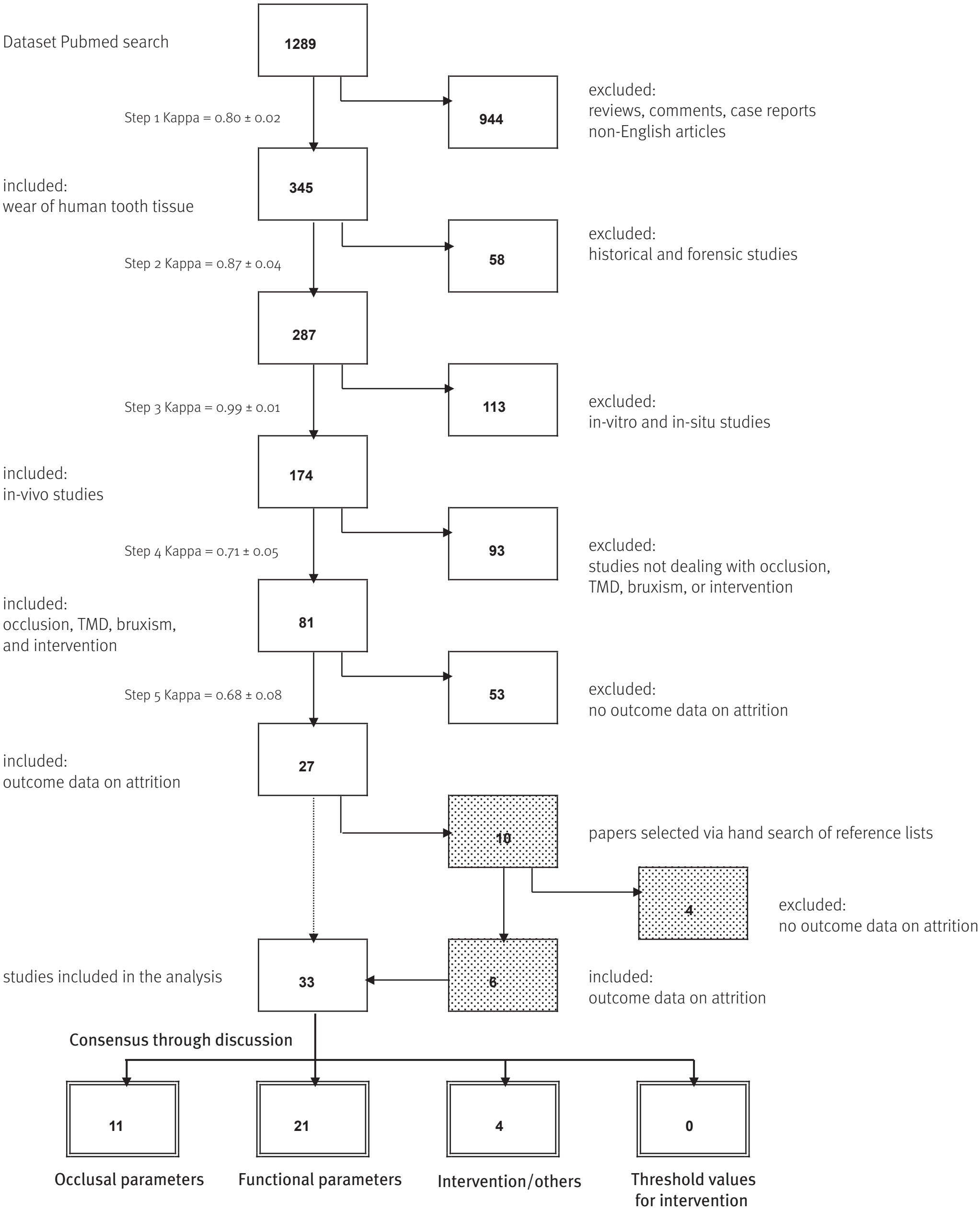

Figure 4.1 Flowchart describing the results of each step in the selection procedure.

*Excluded papers: Krogstad *et al* (1985), De Boever *et al* (1987), Agerberg *et al* (1989), Poynter *et al* (1990).

were small and considered clinically irrelevant. One study found a correlation between reduced number of teeth and increased tooth wear on the remaining teeth [16]. Associations between attrition and anterior (spatial) relationships were reported in several studies, although some of them appear to be contradicting (Table 4.1).

The studies investigating functional parameters in relation to attrition also showed large heterogeneity, making meaningful aggregation of outcome data impossible (Table 4.2). Kim *et al* [22] was the only report addressing 'normal' function. All other reports in this category dealt with TMD or bruxism and as such they were considered addressing dysfunction. A few trends could be distinguished. Seven studies reported positive correlations between attrition and self-reported bruxism. Two studies including self-reported bruxism reported no such correlation. Another study reported no significant correlation between attrition and clinically diagnosed bruxism.

Nine studies reported relationships between attrition and clinically diagnosed TMD, of which three demonstrated positive correlations and one reported a negative correlation. Four studies reported no such correlations. Another study presented positive correlations for some sub-samples of TMD, but not for others. Five studies in this category were based on self-reported TMD symptoms. Of these, two reported a positive correlation between attrition and TMD pain; one reported no such correlation in their results. One study reported a relationship between attrition and temporomandibular joint (TMJ) clicking and another reported no correlation between attrition and symptoms of TMD.

From the intervention/treatment studies (Table 4.3), only one had a prospective study design reporting less attrition in subjects (young children) wearing bites plates compared with subjects who did not wear these devices [23]. This finding was affirmed by Carlsson *et al* [24] who followed subjects with severe attrition and found splint treatment in these subjects to slow down the rate of tooth wear. Two studies were retrospective analyses reporting on relationships between tooth wear and treatment history. Orthodontic treatment history was not associated with attrition [25], whereas extensive restorative treatment and treatments including extraction of teeth seemed to increase the risk for tooth wear [26]. No studies were found addressing interventions at certain threshold values of attrition. One of the included papers [4] mentioned threshold values, but only in relation with the prevalence of tooth wear.

Table 4.1 Studies investigating relationships between attrition and occlusal factors

Reference	Study design	Subject selection	Anticipated risk factor	Number of subjects (controls)	% Female (controls)	Age-group	Tooth wear measurement	Tooth wear scale (levels)
Carlsson et al. 2003 #	L	Population-based	Bruxism, oral parafunctions	320	52	YA	I	5
Witter et al. 2001	L	Dental school patients	Shortened dental arche	74 (72)	60 (51)	A	I	4
Bauer et al. 1997	C	Orthodontically treated	Anterior guidance for anterior wear	85	38	YA + A	I + II	4
Smith & Robb, 1996	C	Population-based	Absent posterior teeth	1007	?	YA + A + E	I	5
Seligman & Pullinger, 1995	C	Dental school patients + private practice patients	Canine attrition	148	32	YA + A	II	5
Abdullah et al. 1994	C	Dental students	Excursive contact schemes	64	47	YA	I + II	4
Johansson et al. 1994	C	Dental students	Excursive contact schemes	80	44	YA	I + II	4
Silness et al. 1993	L	Dental school patients	Vertical overbite and horizontal overjet	51	45	O + YA	II	3
Crothers & Sandham, 1993	C	Referrals wear clinic	Vertical dimensional responses	35 (40)	23 (55)	YA + A	III	mm
Ekfeldt et al. 1990	C	Population-based	Number of teeth	87 (133)	?	YA + A + E	IV	4
Egermark-Eriksson et al. 1987 #	L	Population-based	Occlusal factors/ TMD/bruxism	240	49	Ch + O	I	5

#: reports based on same (original) samples
Study design: L: Longitudinal, C: Cross-sectional
Age-groups: Ch: Children (≤11yrs); O: Adolescents (12-18yrs); YA: Young Adults (19-30yrs); A: Adults (31-64yrs); E: Elderly (≥ 65 yrs)
Tooth wear measurement: I: Clinical examination; II: Cast examination; III: Cephalometric lateral skull radiographs;
IV: Clinical examination + validation by casts
? = Not described, unknown, unspecified
mm = millimeter
+1 = positive correlation; 0 = no correlation; -1 = negative correlation; * = not investigated
+: P<0.05; ++: P<0.01; +++: P<0.001

Correlations between tooth wear and:						
Overbite	Number of teeth	Occlusal guidance scheme	Others	r / ρ / OR values	Level of significance	Remarks
*	*	-1	+1	OR 0.26	+ / ++	Less anterior tooth wear with non-working side contacts. More posterior tooth wear with more horizontal overjet
*	0	*	*			No overall differences between shortened dental arches and complete dental arches. Shortened dental arches existing over 15 years show more wear in premolars
*	*	-1	*	unspecified	++	Less posterior tooth wear with anterior guidance
*	+1	*	*	ρ= 0.20 - 0.51	?	Only small, clinically not significant differences between subjects with or without absent posterior teeth
*	*	*	+1	ρ= 0.45 - 0.58	+	Correlations between canine wear and total posterior tooth wear for ages ‹ 50 yrs; not for ≥ 50 yrs
*	*	0	*			Correlations between posterior + anterior tooth wear and anterior guidance were not significant
*	*	-1 / 0 / +1	*	unspecified	+	With anterior protrusive guidance: more anterior tooth wear and less posterior tooth wear. No correlations between wear and lateral excursive schemes
+1	*	*	*	unspecified	+++	More incisal tooth wear with more vertical overbite
*	*	*	0			No relation between tooth wear and total facial height. Vertical dimension of occlusion compensated by vertical dento-alveolar height change
*	-1	*	*	r2=0.29	+++	The fewer number of teeth, the higher the tooth wear index. Number of occluding teeth was measured but not reported.
*	*	*	+1	r=0.24	+++	More vertical deviation RCP-IP: more tooth wear; unilateral contact in RCP: more tooth wear

Table 4.2 Studies investigating relationships between attrition and function, dysfunction (TMD) or bruxism

Reference	Study design	Subject selection	Anticipated risk factor	Number of subjects (controls)	% Female (controls)	Age-group
Hirsch et al. 2004	C	Population-based	TMD	1011	52	Ch + O
Baba et al. 2004	C	Bruxers and matched controls	Bruxism activity	8 (8)	50	YA
Carlsson et al. 2003 #	L	Population-based	Bruxism, oral parafunctions	320	52	YA
Pergamalian et al. 2003	C	TMD diagnosed subjects	History of self-reported bruxism	84	84	YA
Carlsson et al. 2002 #	L	Population-based	TMD signs and symptoms at young age	320	52	YA
John et al. 2002	C	Dental school patients with diagnosed TMD and controls	TMD	154 (120)	75 (63)	O , YA, A, E
Kim et al. 2001	C	Dental students	Chewing pattern (grinding *vs.* chopping)	15 (15)	33 (33)	YA
Pintado et al. 1997	L	Dental students	Gender, diagnosed TMD	18	?	YA
Magnusson et al. 1994 #	L	Population-based	TMD signs and symptoms	84	45	YA
Pulinger & Seligman 1993	C	Dental school patients + private practice patients	TMD subgroups	270 (148)	89 (32)	YA + A
Goho & Jones 1991	C	School children	Wear facets in primary teeth	50 (50)	?	Ch
Steele et al. 1991	C	Referrals pain clinic and controls	Migraine patients	72 (31)	71 (71)	All age groups
Ekfeldt et al. 1990	C	Population-based	Bruxism	87 (133)	?	YA + A + E
Runge et al. 1989	C	Orthodontic patients	TMJ sounds	226	54	O + A
Seligman et al. 1988	C	Dental students	TMD symptoms	222	46	YA + A

Tooth wear measurement	Tooth wear scale (levels)	TMD/Bruxism diagnosis	Correlation with TMD / Bruxism	r / OR values	Level of significance	Remarks
I	3	S	0			No correlation between anterior tooth wear and TMD pain
II	8	D	0			No significant relationship between tooth wear and current bruxism
I	5	S	+1	OR 12,5	++	Anterior tooth wear at 15 years of age predicts reported tooth grinding at night 20 years later
II	4	D	0			No correlation between tooth wear and TMD pain. Tooth wear not correlated with reported bruxism
I	5	S	+1	OR 4.3	+++	Tooth wear at 15 years of age predicts TMJ clicking 20 years later
II	6	D	0			Anterior tooth wear not significantly associated with TMD
I + II	4				+	Grinding type more posterior tooth wear than chopping type, no difference for anterior tooth wear
II	mm/mm3	S	+1	Δ=0.05 mm3 per year	+	Bruxers show more volume loss per time period than non-bruxers
I	5	S	+1	r=0.39	+	Tooth wear correlated with subjective reports of nocturnal tooth clenching. Degree of tooth wear correlated with TMJ pain on palpation and subjective difficulties in mouth opening
II	5	D	Various	Various		Occlusal etiology role for attrition in TMD subjects remains questioned
I	3	D	0			No correlation between wear facets and clinical signs of TMD
I + II	5	D	0			Migraine group not significant more wear than control group
IV	4	S	+1	r2=0.03	+++	Higher prevalence of bruxisme in subjects with tooth wear compared to subjects without.
I	4	D	+1	unspecified	+	Association between reciprocal clicking and moderate to severe dental wear
II	5	D S	0 1	Z_0=2.78 - 3.69	+	Dental attrition not associated with TMJ clicking. In male: attrition of canines and premolars associated with reported bruxism

Table 4.2 Studies investigating relationships between attrition and function, dysfunction (TMD) or bruxism *(Continued)*

Reference	Study design	Subject selection	Anticipated risk factor	Number of subjects (controls)	% Female (controls)	Age-group
Szentpetery et al. 1987	C	Population-based	TMD	600	53	All age groups
Roberts et al. 1987	C	Referrals TMD clinic	Occlusal factors for arthrogenicTMD	205	?	?
Egermark-Eriksson et al. 1987 #	L	Population-based	Occlusal factors/ TMD/bruxism	240	49	Ch + O
De Laat et al., 1986	C	Dental students	Occlusal parameters for TMD	121	41	YA
Lieberman et al. 1985	C	Population-based	Dysfunction symptoms	369	49	Ch + O
Droukas et al. 1984	C	Dental students	Occlusal factors for dysfunction symptoms in a non-patient group	48	48	YA + A

#: reports based on same (original) samples
? = Not described, unknown, unspecified
Study design: L: Longitudinal, C: Cross-sectional
S = self-reported; D = clinical diagnosis
Age-groups: Ch: Children (≤11 yrs); O: Adolescents (12-18 yrs); YA: Young Adults (19-30 yrs); A: Adults (31-64 yrs); E: Elderly (≥ 65 yrs)
+1 = positive correlation; 0 = no correlation; -1 = negative correlation; * = not investigated
Tooth wear measurement: I: Clinical examination, II: Cast examination
+: P<0.05; ++: P<0.01; +++: P<0.001

Tooth wear measurement	Tooth wear scale (levels)	TMD/Bruxism diagnosis	Correlation with TMD / Bruxism	r / OR values	Level of significance	Remarks
I	2	D, S	+1	unspecified	+	Correlation between excessive tooth wear and dysfunction signs and between excessive tooth wear and reported bruxism
I	4	D	0			No difference between tooth wear in arthrogenic TMD diagnosed subjects and subjects without arthrogenic TMD
I	5	S	+1	r=0.23	+	Tooth wear correlated with reported bruxism for ages 11 and 15 years. No correlation between tooth wear and TMD
I + II	2	S	+1	unspecified	++	More dental wear in subjects with reported bruxism. Dental wear correlated with muscle pain
I	3	D	+1	unspecified	+	Correlation between excessive wear and dysfunction symptoms
I	4	D S	1 0	r= -0.33	+	Negative correlation between attrition of premolars and clinical dysfunction index. No correlation between attrition and reported bruxism

Table 4.3 Studies investigating effects of intervention or treatment history on tooth wear

Reference	Study design	Subject selection	Anticipated risk factor	Number of subjects (controls)	% Female (controls)	Age-group	Tooth wear measurement	Tooth wear scale (levels)
Hachmann et al. 1999	L	Private practice	Bite plate	5 (4)	?	Ch	II	2
Dahl et al. 1989	C	Orthodontially treated	Orthodontic treatment	51 (47)	55 (40)	O	I	5
Dettmar & Shaw 1987	C	Unspecified	Dental treatment	36	33	O + YA	II	mm²
Carlsson et al. 1985	L	Selected cases	Oclusal splints	18	50	YA + A	I + II + III	5

Study design: L: Longitudinal, C: Cross-sectional
Age-groups: Ch: Children (≤11yrs); O: Adolescents (12-18yrs); YA: Young Adults (19-30yrs); A: Adults (31-64yrs)
Tooth wear measurement: I: Clinical examination; II: Cast examination; IV: Photographs
? = Not described

Discussion

The papers included in this review demonstrated that research on tooth wear is a complex undertaking. It appeared that it is difficult to quantify the amount of TSL in a practical way for larger groups of subjects; hence, there is no consensus on how to measure tooth wear clinically. The studies included made use of tooth wear scales ranging from two to eight levels. Very few studies actually measured wear. Relating attrition to other dental factors appeared to be even more complex. The measurement methods determining occlusal factors as well as the diagnosis of functional and dysfunctional 'use' of the dentition as described in the studies showed extensive variation. For example, some studies used anamnestic criteria while others used research diagnostic criteria (RDC/TMD) to diagnose TMD. In other cases, the used measurement methods were not validated. Moreover, it seems to be impossible to isolate specific anticipated risk factors from others, which hinders proper investigation of the multifactorial phenomenon of TSL.

The literature on attrition does not provide clear evidence for the efficacy of particular occlusal designs in the management of attrition. No intervention studies

Study purpose	Outcome
Intervention study on efficay of nocturnal biteplate	Less tooth wear in children treated with bite plate
Effect of orthodontic treatment	Tooth wear not related to yes/no orthodontic history
Effect of treatment history (restorative / orthodontic / extractions) on tooth wear	Heavily restored / extractions / orthodontic + extractions results in more tooth wear than in untreated subjects
Wear rate for moderate / severe tooth wear patients	Low incidence of severe tooth wear in general, splints slow down rate of tooth wear

addressing this topic were found. Some support was found in cross-sectional studies, indicating that anterior (spatial) relationships and attrition were related. As could be expected, anterior guidance, which is partially determined by vertical overbite and horizontal overjet, seems to reduce the risk for posterior attrition, but increases the risk for anterior attrition. Clinically, canine protection is advocated to ensure anterior guidance with the purpose of diminishing posterior TSL. In this review, one study addressed this variable, demonstrating an association between canine wear and posterior wear [3]. It has to be emphasized that this was the case for unrestored teeth and was therefore not directly applicable for restored teeth. Based on the literature though, a treatment strategy to create canine guidance thus remains unproven. The literature provides no data regarding the amount of lost tooth tissue due to attrition for different occlusal schemes. Whether the occurrence of anterior TSL is more or less a threat to the dentition or its function than posterior TSL remains a subjective issue.

The articles addressing the relationship between attrition and the level of posterior support found that decreased support does not lead to more wear. Hence, there is no justification for tooth replacement to prevent TSL in the remaining dentition. Nevertheless, the multi-factorial aetiology of TSL is a too complicated a factor to draw such conclusions.

Most studies identifying relationships between attrition and functional or dysfunctional parameters, addressed the question whether these parameters could be the cause for attrition. Bruxism was identified as an associative factor in dental attrition in most of the studies. However, as all of these associations were based on self-reported bruxism, they are lacking a sound methodological basis [27]. The information on bruxism attained from the subjects might not be reliable, because many individuals are not aware of their parafunctions [28]. One study concluded that attrition was not increased in subjects with diagnosed bruxism [29], but due to the small sample size and the short experimental period covered, this study might have been insufficient for this conclusion.

With regard to possible associations between attrition and TMD signs and symptoms, synthesis of study outcomes is even more difficult. As time goes by, TMD symptoms may vary. TSL on the other hand has a cumulative character: lesions do not heal but will stay constant even if (some of the) aetiological factors disappear. Comparing TMD patients with non-patients in studies on TSL is therefore less accurate than often assumed. Moreover, the 'degree of dysfunction' is often not measured, in contrast to the 'degree of TSL'. It is therefore very difficult (if not impossible) to combine data from different studies using subjective and objective TMD-criteria with data from studies using different tooth-wear scales (varying from two to eight levels) in an attempt to calculate relative risks for TSL in case of TMD.

Elements of the healthy dentition have been described as absence of pathology, sufficient oral function, variability in forms and function, and the ability to adapt to changing function or environment [30,31]. If attrition is hypothesized as a mechanism to adapt to changing function or environment, it might explain the weak correlation between attrition and TMD; lack of ability to adapt is claimed to cause TMD. However, the two selected studies that investigated attrition as possible cause for dysfunction are ambiguous in this respect. In one study, wear facets in primary teeth did not predict clinical signs of TMD [32]. In contrast, the other study [19,33] pointed out that attrition at young age predicts TMJ clicks and night grinding 20 years later. Unfortunately, we found only one intervention study [23] relevant to our topic. This study reported on the effect of a non-restorative therapy (biteplate) to reduce attrition [23]. The two included retrospective studies [25,26] cannot be considered intervention studies. They did not compare the true effects of one treatment to another, but merely looked at TSL as a side effect of variable treatments in the past. It is possible that another search strategy, e.g., using the keyword 'bruxism' in combination with 'intervention' or 'treatment', would have revealed more intervention studies. However, most probably TSL would not have been included as a research variable in those studies designs. Nevertheless, some remarks can be made regarding our search strategy. The additional hand search on the basis of the full-text articles revealed that six relevant papers had to be included instead of their exclusion on the basis of abstracts and titles. Three of them [14,16,17] were actually included in the original PubMed list of 1289, but did not meet later selection criteria. The other three [12,13,15] were not excavated by PubMed due to the absence of logic keywords. The heterogeneity in terminology used by investigators emphasizes the need for standardization of study and reporting protocols. It also emphasizes the importance of additional hand searches in systematic reviews.

Conclusions

This systematic review failed to find sound evidence for the recommendation of one occlusion-based treatment protocol above another in the management of attrition. The null-hypothesis is therefore accepted. Some correlations were found between attrition and anterior spatial relationships, however not in the context of intervention. Absent posterior support did not necessarily lead to increased attrition of the remaining teeth, whereas a reduced number of teeth may lead to increased wear of the remaining teeth. Correlations between attrition and other occlusal parameters were not reported. Attrition seems coexistent with self-reported bruxism. Reports on attrition and TMD signs and symptoms provide little understanding of the relationship between the two. No papers were found that reported threshold values of attrition that indicate whether intervention might be beneficial for a patient.

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5

Body Position and Occlusal Contacts in Lateral Excursions: A Pilot Study

Van 't Spijker A, Creugers NHJ, Bronkhorst EM, Kreulen CM. **Body Position and Occlusal Contacts in Lateral Excursions: A Pilot Study.** *Int J Prosthodont* 2011;24:133–136.

Abstract

This pilot study aimed to explore whether occlusal contacts during lateral excursions are influenced by tilted body positions. Occlusal contacts in lateral excursions were verified for 30 dental students and 22 dental staff members using articulation foil while patients were seated in a dental chair. The number and location of dynamic tooth contacts (initial and halfway) were registered with the back of the dental chair in three positions: upright, 45 degrees, and supine. For the majority of subjects (96%), dynamic occlusal contacts changed when the body position was altered.

Introduction

It is recognized that patients may indicate different perceptions of occlusal contacts with static and dynamic occlusion in an upright position compared to supine. However, to the authors' knowledge, hardly any scientific data are available on the appearance of occlusal contacts in different body positions. One study that investigated static occlusion was located, and it was observed that jaw closure in tilted body positions resulted in different initial occlusal contacts [1]. Since data on dynamic occlusion are lacking, the aim of this pilot study was to explore if tooth contacts during lateral excursions are influenced by tilted body positions.

Materials and Methods

A convenience sample of 30 students (22 to 34 years of age; 8 men, 22 women) and 22 faculty staff members (31 to 64 years of age; 11 men, 11 women) from the Radboud University Nijmegen Medical Centre, Nijmegen, The Netherlands, participated in this pilot study. All subjects had complete dentitions and were free of any signs or symptoms of temporomandibular disorder. While seated in a dental chair, subjects were instructed to perform a lateral excursion from maximal occlusion to the point where the canines were in an end-to-end position. Shim stock articulation foil, held by a pair of pincers, was used to check the presence of occlusal contact during lateral excursion (Figure 5.1). Working and nonworking side contacts were subsequently registered. Following the method of Ogawa *et al* [2], occlusal contacts in the initial and terminal portions of the excursion were differentiated.

Registrations were performed for three separate body positions. For this purpose, the position of the back of the dental chair was altered so that the subjects' Frankfort plane was at different angles to the floor: horizontal (upright), 45 degrees, and vertical (supine) (Figure 5.2). The headrest supported the head in all positions to prevent unnecessary tension in the supra- and infra-hyoid muscles [3]. One trained observer conducted the registrations. Intra-observer reliability was determined by re-examining 10 subjects (Cohen $\kappa = 0.74$).

Frequencies of the changes in occlusal contacts resulting from tilting the body position were calculated. For each body position, the type of dynamic occlusion was registered and defined as canine guidance, anterior guidance or group function (Figure 5.3). Deviating occlusal guidance schemes were shared among "other types of guidance".

Figure 5.1 Shim stock articulation foil was used to check the presence of occlusal contacts during lateral excursion.

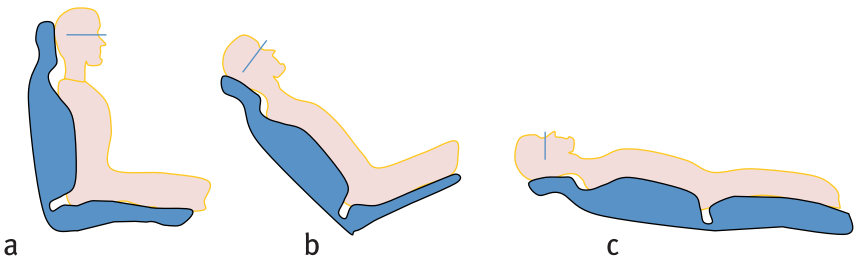

Figure 5.2 Registrations were taken with the dental chair in three positions: (**a**) upright (horizontal), (**b**) 45 degrees, and (**c**) supine (vertical). The line drawn represents the Frankfort plane.

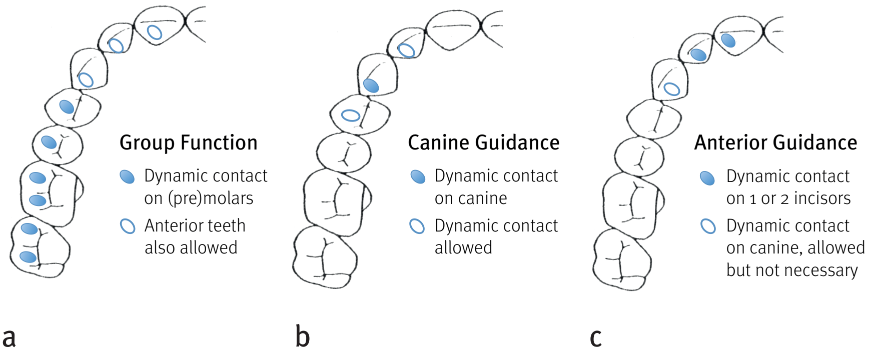

Figure 5.3 Criteria used to define the type of occlusal guidance during lateral excursion: (**a**) group function, (**b**) canine guidance, and (**c**) anterior guidance.

Results

The majority of subjects had canine guidance (44%) or group function (40%) in the upright position (Table 5.1).

Tilting the body position from vertical to horizontal did not show a specific change in the subjects' type of dynamic occlusion. For instance, two subjects with canine guidance in the upright position changed to group function and one changed to anterior guidance when moved to the 45 degrees position, while three subjects changed to canine guidance. The number of changed tooth contacts per subject ranged from 0 to 22 (Table 5.2).

Two subjects (4%) had no change in tooth contacts. Nearly 83% of subjects had 7 or more changes in tooth contacts on the working side, while 48% had 7 or more changes on the nonworking side (Table 5.3).

Table 5.1 Number of subjects (n = 52) with canine guidance, anterior guidance, group function, or other types of guidance per body position

	Left					Right				
	Up-right	When altered into '45 degrees', changed to:	45 degrees	When altered into 'Supine', changed to:	Supine	Up-right	When altered into '45 degrees', changed to:	45 degrees	When altered into 'Supine', changed to:	Supine
CanG	27	AntG: 1	26	AntG: 2	22	20	AntG: 0	23	AntG: 1	21
		GroF: 2		GroF: 2			GroF: 1		GroF: 2	
		OtherG: 1		OtherG: 0			OtherG: 0		OtherG: 0	
AntG	6	CanG: 1	9	CanG: 1	7	5	CanG: 0	5	CanG: 0	6
		GroF: 0		GroF: 2			GroF: 1		GroF: 0	
		OtherG: 0		OtherG: 0			OtherG: 0		OtherG: 0	
GroF	18	CanG: 2	15	CanG: 0	20	26	CanG: 4	23	CanG: 1	23
		AntG: 2		AntG: 0			AntG: 1		AntG: 0	
		OtherG: 0		OtherG: 0			OtherG: 0		OtherG: 1	
OtherG	1	CanG: 0	2	CanG: 0	3	1	CanG: 0	1	CanG: 0	2
		AntG: 0		AntG: 0			AntG: 0		AntG: 0	
		GroF: 0		GroF: 0			GroF: 0		GroF: 0	
Total	52	9	52	7	52	52	7	52	5	52

CanG = Canine guidance; AntG = Anterior guidance; GroF = Group function; OtherG = Othr types of guidance.

Table 5.2 Number of dynamic occlusal contacts per body position

	Upright	45 degrees	Supine
Working side	219	216	225
Nonworking side	35	47	45
Total	254	263	270

Table 5.3 Number of subjects according to the number of changed dynamic occlusal contacts on working and nonworking sides

No. of changed occlusal contacts	Upright to 45 degrees	45 degrees to supine	Upright to supine	Changes from all positions
Working side				
0	3	2	2	2
1	2	2	1	0
2	9	12	6	1
3	9	9	11	0
4	14	13	12	0
5	5	4	7	2
6	5	4	7	4
7+	5	6	6	43
Total	52	52	52	52
Non working side				
0	3	2	2	2
1	1	2	3	0
2	25	24	26	1
3	11	13	7	1
4	6	4	8	0
5	6	5	4	1
6	0	2	1	22
7+	0	0	1	25
Total	52	52	52	52

Discussion

In the present study, the intra-observer agreement was good, indicating that the use of shim stock foil is valid [4]. However, the reliability of recordings of dynamic occlusion also depends on the accuracy and reproducibility of the repeated jaw movement, whereas consistent occlusal forces are very difficult to control and may vary each day [5]. Given a certain variation among subjects, the high value for agreement is likely to be an underestimation of the accuracy of the use of shim stock foil.

From the results, it appears that the frequency of changes in occlusal contact during lateral excursions resulting from altering the body position differs largely between subjects. Few subjects showed unchanged occlusal contacts, but structural changes in the type of occlusion from different body positions are not conceivable. Therefore, it is not clear whether recordings for extended occlusal rehabilitation should be performed in an upright or supine position. However, this pilot study illustrates that it is advisable to assess static and dynamic occlusion in more than one body position. This study describes a relationship between body position and the manner in which occlusal contacts are presented. It is unknown to what extent this might induce modified therapeutic occlusal adjustment protocols.

Conclusion

For the majority of subjects, the number of dynamic occlusal contacts changed when the body position was altered.

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6

Assessment of early attrition using an ordinary flatbed scanner

Van 't Spijker A, Kreulen CM, Bronkhorst EM, Creugers NHJ. **Assessment of early attrition using an ordinary flatbed scanner.** *Journal of Dentistry* 2012;40:603-8.

Abstract

The aim of this study was to assess a two-dimensional method to monitor occlusal tooth wear quantitatively using a commercially available ordinary flatbed scanner.
Materials and methods: A flatbed scanner, measuring software and gypsum casts were used. In Part I, two observers (A and B) independently traced scans of marked wear facets of ten sets of casts in two sessions (test and retest). In Part II, three other sets of casts were duplicated and two observers (C and D) marked wear facets and traced the scanned images independently. Intra- and inter-observer agreement was determined comparing measured values (mm^2) in paired T-tests. Duplicate measurement errors (DME) were calculated. Results: In Part I the test and retest values (10 casts, 218 teeth) of observer A and B did not differ significantly (A: $p = 0.289$; B: $p = 0.666$); correlation coefficients were 0.998 (A) and 0.999 (B). ‘‘Tracing wear facets’’ showed a DME of 0.30 mm^2 for observer A and 0.15 mm^2 for observer B. In Part II, assessment of 70 teeth resulted in correlation coefficients of 0.994 for observer C and 0.997 for observer D; no differences between test and retest values were found for C ($p = 0.061$), although D differed significantly ($p = 0.000$). The DME for ‘‘marking and tracing wear facets’’ was 0.39 mm^2 (C) and 0.27 mm^2 (D). DME for inter-observer agreement were 0.45 mm^2 (test) and 0.42 mm^2 (re-test).
Conclusion and clinical relevance: We conclude that marking and tracing of occlusal wear facets to assess occlusal tooth wear quantitatively can be done accurately and reproducibly.

Introduction

Several studies indicate that tooth wear is a health problem in dentistry [1,2]. Although there is no consensus about the prevalence and severity amongst patients, studies indicate that tooth wear is increasingly relevant [3,4]. Clinical experience in general practice does seem to confirm these data. One of the aspects that can be related to this inconclusiveness is the use of differing methods to record the degree of wear. In cross-sectional clinical studies, tooth wear indices such as those by Eccles [5], Smith and Knight [6], Lussi [7] and Bartlett *et al* [8] have been used. These indices use a list of criteria to grade the severity of the loss of tooth substance and they have shown to be reasonably reproducible.[9] Variations to the proved indices are often used in studies on erosion [10–13]. Inter-observer variation can be substantial while wear of individual teeth is hard to monitor using indices. Grading methods therefore have limitations to observe tooth wear longitudinally in patients in general dental practice, or in longitudinal observational studies. An index generally detects relatively gross differences, and the exact location of the wear on a tooth cannot always be laid down. In addition, it is difficult to record differences in tooth wear in a relatively short timespan [14].

In the monitoring of tooth wear, it is a challenge for both researchers and clinicians to find a method that detects small differences, that is rapid, easy to use and affordable in general dental practice. Two consecutive sets of gypsum casts with an interim period of some years can provide the clinician a reference to visualize the progression of tooth wear. Making casts is a conventional method to register the dental status accurately [15] and comparing two scanned models would be a solution to quantify the loss of tooth tissue. Pintado *et al* [16] stated that: the most common method to report wear rates in dentistry, was by depth, but measurement of depth only can give the observer a completely different idea about progression of wear than measurement of volume-loss. Measurement of surface areas only will give the observer a limited view on the process, as facet areas can change in contour but remain unchanged in outline. Highly accurate three-dimensional scanning systems are available [17–20]. Generally the more sophisticated digital techniques provide better accuracy and more extensive information regarding the entire occlusal surface wear of the (restored) tooth [21]. However they are too expensive and time-consuming to be used in clinical studies with many patients involved. The process of scanning and calculation is time-consuming and the information obtained might be too detailed. Assessment of a selection of teeth will narrow the view and perhaps give a wrong impression of the process, as wear can occur on other teeth than those selected. Chadwick *et al* [22] developed a system to assess palatal tooth wear longitudinally using surface mapping, and found it to be both accurate and reproducible.

Haketa *et al* [23] accepted the limited view of two-dimensional assessments and made standardized photographs of the occlusal surfaces of gypsum casts. Before photographing, wear facets were marked manually with a pencil and ink. The recorded areas of the facets per tooth were subsequently measured on the calibrated images. By doing this, a three-dimensional registration was transferred to a two-dimensional recording. Yet, the authors have indicated that this technique is useful to determine the severity of tooth wear, and accuracy and precision were high. While standardized photographing is tenuous, it would be easier for a general practitioner and clinical researcher to scan the occlusal surfaces of casts by means of a standard flatbed scanner, which is widely available. This registration method does not require a precise optical set-up as used by Haketa *et al* [23] and for longitudinal purposes it seems easier to relocate the models towards the registration equipment. Still, its validity needs to be determined.

The aim of this study is to determine the reliability and reproducibility of a two-dimensional method to monitor tooth wear using a flatbed scanner and gypsum casts. We hypothesize that the method is accurate and precise although the two main procedural steps, marking the facets and measuring the scans, differ in their intra- and inter-observer variability.

Materials and methods

Part I

Ten subjects with tooth wear were randomly selected from the group of 52 subjects with complete dental arches that were included in a study on occlusal tooth contact registration at the Nijmegen Dental School [24]. The selected 10 subjects, 4 males and 6 females, were 29–49 years old. Full arch impressions of the dentitions were made by an experienced clinician using a stock tray (Border-lock®, Clan dental products) and silicone impression material (Aquasil XLV®, Denstply). Occlusal surfaces of the teeth were coated with silicone before inserting the tray in order to minimize the risk of voids in the impression material. The impressions were poured in vacuum-mixed dental stone (Fuji Rock®, GC) according to the manufacturer's instruction. After setting of the gypsum, the cast bases were trimmed to regular forms. Structures in the cast not being part of the dental arch were removed in order to put the cast upside down on a horizontal surface with the occlusal surfaces in maximal contact with the underground, e.g. the ascending part of the mandible (ramus mandibula) of the casts of the lower jaw often had to be removed. To avoid optical side effects, casts were individually placed in the centre of the flatbed scanner.

The wear facets that could be observed on the incisal, occlusal, buccal and palatal surfaces of all teeth in the upper jaw cast and lower jaw cast were marked with a thin pencil (HB; 0.5 mm) by one experienced operator (AvtS) (Figure 6.1). The casts were placed upside down on the glass plate of a commercially available flatbed scanner

(Epson Perfection 4490 Photo®). It was verified that the occlusal surfaces of the casts were in contact with the glass plate of the scanner. A common cardboard box of non-specific dimensions was used to cover the cast to ensure standardized exposure (Figure 6.2). Scans were made with a 600dpi resolution. A calibrated ruler (Peak Optics®, USA) was scanned with every cast as reference in the calibration of the images. Thereafter, image analysis software (Leica Qwin®) was used to trace the drawn circumferences of the facets manually by use of the mouse; the image of the model was displayed on a 17-inch computer screen with a resolution of 1280 × 1024 pixels. The software automatically calculated the surface area of the traced contour ("projected" facet) with the outcome measure in mm². Two observers performed this procedure independently. They were undergraduate dental students who underwent a thorough training by the principal investigator (AvtS). Each observer performed a test and re-test recording with an interim period of at least 1 week.

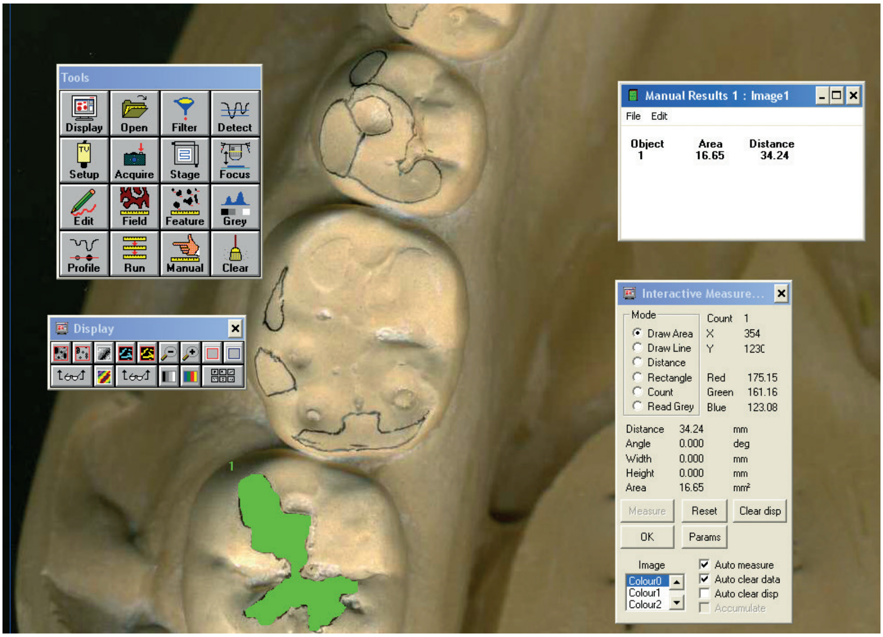

Figure 6.1 The marked areas of tooth 37 are traced manually and the surface of the area is computed; a reference ruler was scanned with every cast to ensure correct calibration.

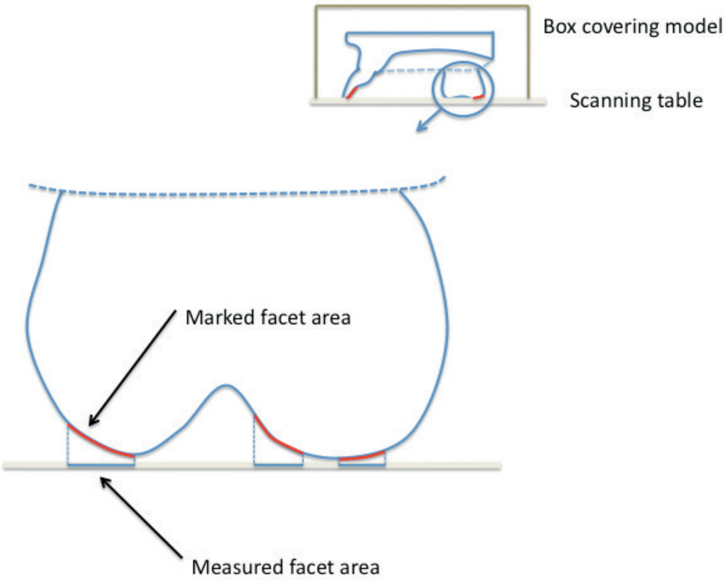

Figure 6.2 A cardboard box covered the casts while scanning. The images of the marked areas were measured in mm^2.

Part II

On the assumption that the method of tracing wear facets as described in Part I was sufficiently reliable, this part of the study was directed to the accuracy of marking wear facets on gypsum casts. From the 52 subjects of the occlusal tooth contact study [24], three subjects were selected. They were not included in the ten subjects from Part I. The three subjects were female, two were 22 years old, one was 23 years old.

Identical to Part I, full arch impressions of the dentitions and subsequent castings were made. A silicone master mould (Silflex®, Elephant Dental) was made of each cast, and this master was poured with gypsum four times.

Two observers marked the wear facets on the copy-models the same way as in Part I. They excluded teeth with (extended) restorations involving one or more cusps and only included facets that could clearly be matched to occlusal contact. Each observer independently assessed two identical upper and two identical lower copy-models of each subject. The marked models were subsequently scanned with the same procedure as described in Part I. Tracing of the marked facets on the computer screen images was done once, each observer traced the own marked wear facets. The observers were undergraduate dental students (two others compared to Part 1) who underwent a thorough training by the principal investigator (AvtS).

Statistical analyses

In Part I, intra- and inter-observer reliability of tracing the marked contours on the computer screen was assessed with paired T-tests on all surface areas included by the traced contours per tooth as recorded by observers A and B in the tests and re-tests. Correlation coefficients of the first and second values of each observer were determined. The duplicate measurement error (DME) was calculated by dividing the Standard Deviation as calculated in the paired T-test by $\sqrt{2}$.

In Part II, intra- and inter-observer variability of marking the wear facets on identical casts was assessed by paired T-tests as well. The difference between computed surface areas of the models marked by observers C and D was used as an indicator of inter-observer reliability.

Results

In Part I, observers A and B each assessed wear facets on 218 teeth with a range of 0.85–42.82 mm² wear facet area per tooth. As shown in Table 6.1, the mean wear facet areas for the test and re-test, were 9.23 and 9.22 mm² for observer A, and 9.19 and 9.20 mm² for observer B. No significant differences between tests and re-tests values were found for observer A or for observer B. The duplicate measurement error (DME) for observer A was 0.30 mm², and the DME for observer B was 0.15 mm². There were no significant differences when DME for wear facets on front teeth (generally smaller wear facets) were compared to DME for wear facets on molars and premolars (generally larger wear facets). Correlation coefficients were 0.998 ($p < 0.001$) for observer A and 0.999 ($p < 0.001$) for observer B.

Table 6.1 Mean wear facet areas for the four observers in Part I and II

	Test	Re-test	
	Mean area in mm²	Mean area in mm²	Paired T-test
Part I			
Observer A	9.23 (±6.71)	9.22 (±6.63)	p=0.666
Observer B	9.19 (±5.84)	9.20 (±5.84)	p=0.289
Paired T-test	p=0.521	p=0.446	
Part II			
Observer C	5.74 (±4.73)	5.86 (±4.85)	p=0.061
Observer D	5.85 (±4.71)	6.01 (±4.83)	p=0.000
Paired T-test	p=0.153	p=0.008	

Paired T-test revealed no significant differences between observer A and B for test or retest recordings. The correlation coefficients were 0.817 ($p < 0.001$) and 0.820 ($p < 0.001$) for the test and re-test recordings respectively. Figure 6.3 depicts the scatter plot of the (initial) test recordings of observers A and B.

In Part II, observers C and D each assessed wear facets on 70 teeth; wear facet areas ranged from 1.02 mm² to 21.55 mm² per tooth. As shown in Table 6.1, the mean wear facet areas for the test and re-test, were 5.74 and 5.86 mm² for observer C and 5.85 and 6.01 mm² for observer D. Consistently higher scores on the second casts of observer D probably cause the difference between observer C and D, as no significant differences between measured values of the two different casts were found for observer C but they were found for observer D. The DME for observer C was 0.39 mm², and 0.27 mm² for observer D. Correlation coefficients of the two recordings were 0.994 ($p < 0.001$) for observer C and 0.997 ($p < 0.001$) for observer D. No significant differences were found when first recordings of observer C were compared to those of observer D, but they were found when the measurements of the second casts of observer C and D were compared.

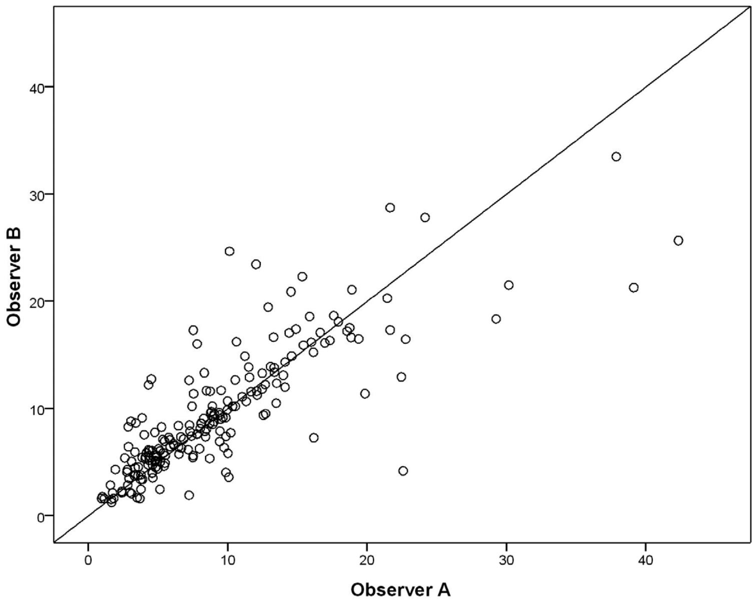

Figure 6.3 Part I: Initial recordings of observer A (horizontal axis) and initial recordings of observer B (vertical axis) in mm² (n = 218); the correlation coefficient was 0.817 ($p < 0.001$).

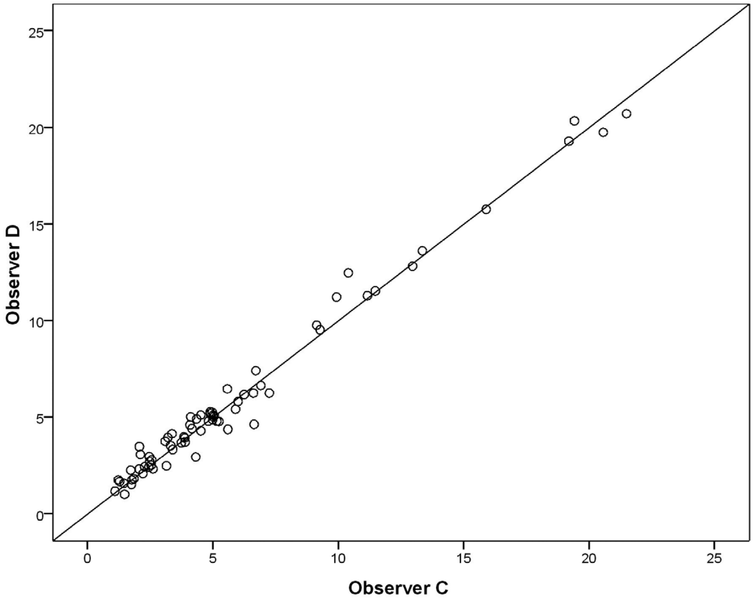

Figure 6.4 Part II: The recordings of the first casts by observer C (horizontal axis) and observer D (vertical axis) in mm² (n = 70); the correlation coefficient was 0.991 ($p < 0.001$).

Figure 6.4 illustrates the correlation of the first recordings of observers C and D ($R = 0.991$, $p < 0.001$); the second recordings showed a similar picture ($R = 0.993$, $p < 0.001$). However, the DME for the inter-observer comparison was found to be 0.45 mm² for the recordings of the firsts casts and 0.42 mm² for the recordings of the second casts.

Discussion

The results show that defining the outline of wear facets on the study models is the most critical step in the whole procedure, while tracing the scanned image is the most reproducible; measurement of wear facets using a two-dimensional system can be done accurately and reliably. In a pilot study to mark wear facets on casts with the same dataset as Part II, the principal investigator (AvtS) reached a DME of 0.47 mm². Therefore we conclude that in consecutive measurements of wear facets (e.g. in longitudinal studies) a standard error of approximately 0.50 mm² should be taken into account.

In essence, our method to measure the amount of occlusal tooth wear is comparable to the method of Haketa *et al* [23]. After marking the facets on casts, they used a CCD camera in a fixed setting to record and measure the surface areas. This made the method difficult to reproduce and not suitable to use in general practice or large-scale clinical studies. The regular flatbed scanner in our study made the method easier to apply in practice than using the camera. Haketa *et al* [23] described that instruction and training of the examiners was necessary. To obtain an individual outcome per tooth, the measured surface of the wear facet was divided by the total occlusal area of each tooth and this relative tooth wear score ranged from 0 (no tooth wear) to 1.0 (completely worn occlusal surface). Registration of both wear facets and total occlusal surface areas might introduce measurement errors, but the method appeared to be accurate and precise, with an interclass correlation coefficient ranging from 0.85 to 0.91. This result correlates well with our results. The found correlations do not imply that the system can be used to give an absolute description of the process, or assess al types of tooth wear, but it provides the observers a view to location and relative increase of wear facet areas.

The disadvantage of a two-dimensional system is that changes in the vertical direction are not registered. Surfaces that are not perpendicular to the scanning table are depicted smaller than the actual surface area on the cast. Changed angulations and inclinations of teeth in a longitudinal study will induce changes that will hamper calculation of increase in wear facets as well. Therefore the results of the two-dimensional method should be regarded as a method to only detect the relative increase of the outline of wear facets. By selecting only those wear facets that can be matched to occlusal contact, we tried to restrict the analysis to attrition. To verify that only these contacts are being assessed one could use articulation foil or bite registration material and place them on the gypsum casts. Tooth wear that has progressed to a stage that includes the complete occlusal area, or tooth wear that does not lengthen the outline of the wear facet, but just deepens the facet (for example in cases of cupping or pitting), are not recognized in a two-dimensional system.

A three-dimensional method will register absolute volume changes. Apart from costs, the efforts of making the registrations and doing the calculations merit the use of more simple methods in clinical dental practice and larger observational studies. It does not always seem meaningful to measure as precise as possible, for the purpose of the study will demand the design and precision, which will determine the method to assess tooth wear. Nevertheless, it is a challenge to calibrate and compare the accuracy of two- and three-dimensional systems.

To our knowledge, no measuring system has unambiguously proven to be simple and suitable to be used in a clinical setting as a general dental practice. In both two-dimensional and three-dimensional systems, the outline of a wear facet needs to be detected and marked, making the measurement and calculations dependant on the accuracy of the operator. Even in software that automatically superimposes two models, the evaluation of the best fit is dependant on the similarity of the casts and the scans, and the limits in the parameters as determined by the operator. As commercially available intra-oral three-dimensional scanning systems are becoming more capable to export data suitable for calculation, we expect these systems to have a large potential in longitudinal studies on tooth wear. Still, the analysis will be time-consuming as changed angulations or rotations of individual teeth will disturb rapid full-arch analysis. When attrition is suspected, the used two-dimensional scanning system using an ordinary scanner offers a relatively simple and affordable method to monitor the progression of tooth wear in an early stage. From our experience it was not very difficult to calibrate two relatively inexperienced observers and we expect that it will be quite simple to train general practitioners or clinical researchers in marking wear facets on gypsum casts.

Conclusions

The aim of this study was to determine the reliability and reproducibility of a two-dimensional method to monitor occlusal tooth wear using an ordinary flatbed scanner and gypsum casts. The marking of wear facets on gypsum casts can be done accurately and precise; a good inter-observer reliability, and good intra-observer reliability was found. Digital tracing of scanned wear facets has a high intra- and inter-observer reliability.

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7

Occlusal wear and occlusal condition in a convenient sample of young adults

Van ‘t Spijker A, Kreulen CM, Bronkhorst EM, Creugers NHJ. **Occlusal wear and occlusal condition in a convenient sample of young adults.** *Journal of Dentistry* 2015;43:72-77.

Abstract

Objective: to study progression of tooth wear quantitatively in a convenient sample of young adults and to assess possible correlations with occlusal conditions.
Methods: Twenty-eight dental students participated in a three-year follow up study on tooth wear. Visible wear facets on full arch gypsum casts were assessed using a flatbed scanner and measuring software. Regression analyses were used tot assess possible associations between the registered occlusal conditions 'Occlusal guidance scheme', 'vertical overbite', 'horizontal overbite', 'depth of sagittal curve', 'canine Angle class relation', 'history of orthodontic treatment', and 'self-reported grinding / clenching' (independent variables) and increase of wear facets (dependent variable).
Results: Mean increase in facet surface areas ranged from 1.2mm^2 (premolars, incisors) to 3.4mm^2 (molars); the relative increase ranged from 15% to 23%. Backward regression analysis showed no significant relation for 'group function', 'vertical overbite', 'depth of sagittal curve', 'history of orthodontic treatment' nor 'self-reported clenching. The final multiple linear regression model showed significant associations amongst 'anterior protected articulation' and 'horizontal overbite' and increase of facet surface areas. For all teeth combined, only 'anterior protected articulation' had a significant effect. 'Self reported grinding' did not have a significant effect ($p > 0.07$).
Conclusions: In this study 'anterior protected articulation' and 'horizontal overbite', were significantly associated with the progression of tooth wear. Self reported grinding was not significantly associated with progression of tooth wear.
Clinical Significance: Occlusal conditions such as anterior protected articulation and horizontal overbite seem to have an effect on the progression of occlusal tooth wear in this convenient sample of young adults.

Introduction

During the last decades an increase in the annual number of published studies on tooth wear and especially on erosive tooth wear can be observed [1]. From these studies it appears that more occlusal tooth wear can be found with an increasing age [2]. The majority of the data that demonstrate this wear-age relation stem from cross sectional studies. Although the cross sectional study design is appropriate to study trends in large groups of people, recall of specific individuals after an interim period is not anticipated, which hinders accurate longitudinal observations. Particularly, assessment of the dynamics in occlusal tooth wear needs individual monitoring over time instead of studying different cohorts at different observation moments as in cross sectional studies. However, prospectively collected data from individual patients are not widely available [3,4,5].

The relationship between occlusal wear and occlusal conditions is subject of discussion and there are some indications that atypical tooth wear can be related to specific occlusal conditions [6]. Although outcomes from cross sectional studies indicate that there is no significant association between the type of dynamic occlusion and tooth wear status [7,8], there are also indications that the spatial relationship of anterior teeth (Angle class, inclination and overbite) is of influence [9]. Nevertheless, case reports on the rehabilitation of worn dentitions often state that, from a preventive perspective, anterior guidance needs to be (re) established [10]. To elucidate the relationship between occlusal factors and tooth wear, individual monitoring is needed.

Tooth wear is mainly assessed by means of indices with ordinal scales. The diversity in used tooth wear indices makes it difficult to compare results. Moreover, several investigators agree that most indices cannot detect localized wear nor minor changes in tooth wear status. An alternative to assessing wear facets using ordinal indices is direct measurement of changes in the surface area of the wear facets that generate data for subtraction techniques. These quantitative methods are exact and reliable, but most often extensive and time consuming. In a previous report, we studied the reproducibility of a simple method to measure tooth wear using a flatbed scanner and measuring software [11]. Such method does not need sophisticated instruments, is reliable and is suitable to monitor early stages of occlusal tooth wear.

The purpose of this prospective follow-up study is to monitor occlusal tooth wear in a convenient sample of young adults and to assess associations of different occlusal conditions with changes in occlusal tooth wear facets.

Materials and methods

Participants

Thirty dental students (age 24.7 ± 2.6 years at the end of this study; 8 males and 22 females) from a cohort of 64 first years' students of the Nijmegen Dental School volunteered to participate in this follow-up study [12]. They agreed upon the purpose of the study and agreed to attend both baseline (T_0) and 3-years recall (T_3). One participant was excluded because of missing recall data. Furthermore, it was expected that all participants, being young adults, had complete dental arches, but one participant had a dental status that was not comparable to the others (missing teeth and cross bite) and was excluded for this reason. No subjects were excluded due to severe tooth wear status. It appeared that the tooth wear that was visible did not exceed the Tooth Wear Index by Smith and Knight [13] (TWI) score 2; only wear limited to enamel and early exposure of dentine was present. Finally, 28 (6 male, 22 female) students were included in this study.

Registrations

Clinical registrations were made at T_0 and relevant dental history was noted. Occlusal guidance scheme was determined by clinical registration of the contacts between maxillary and mandibular teeth during lateral excursions (Table 7.1) and recorded as [14]: (1) incisor protected articulation (incisors disengage the posterior teeth in the excursive movements of the mandible, (2) canine protected articulation (canines disengage the posterior teeth in the excursive movements of the mandible), or (3) group function (multiple contact relations between the maxillary and mandibular posterior teeth in lateral movements). For this purpose a 12µm polyethylene foil (Shim Stock, Hahnel) was hold and pulled between antagonistic teeth with the participants sitting in an upright position [12].

Full arch impressions were taken using stock trays (Clan dental products) and a silicone impression material (Aquasil, Dentsply). The occlusal relationship between maxilla and mandible was recorded with a silicone registration material (Futar, Kettenbach). Impressions were poured in dental stone (Fuji Rock, GC). All casts were trimmed so that they could be placed on a scanning table with the occlusal surface in contact with the horizontal surface.

For the casts at T_0, canine Angle classification, depth of sagittal curve (Von Spee curve), and anterior overbite (horizontal and vertical) were assessed (Table 1). Similar to the method described by Lie et al [15], a metal bar was positioned on the canine and on the most distal cusp of the last molar, and the height difference of the perpendicular line towards the lowest cusp of the arch was measured for each mandibular side using a vernier caliper. Horizontal and vertical overbite were assessed relative to the buccal surfaces of the central incisors and measured with the vernier caliper, which had an accuracy of 0.05mm (WEZU Measuring Tools GmbH).

At T_3, dental casts were made according to the same procedure as described above. To the question whether participants were conscious of clenching and/or grinding during the previous observation period, 17 responded positively to clenching, 8 to grinding and 25 to both clenching en grinding. None of the participants was wearing a night guard or splint during the observation period, underwent orthodontic treatment nor received restorations in more than 3 teeth.

Tooth wear assessment

At T_0 and T_3 wear facet surface areas (FSA) of all teeth were measured on the casts with a previously described flatbed scanner method [11]. Wear facets that could be related to occlusal contacts, were marked with a sharp pencil (HB, 0.5mm). Each marked cast was placed on the scan table of a flat bed scanner (Epson Perfection 1680) with the cusps in contact with the scan table. After scanning, the images of the marked surface areas were traced and the areas calculated and expressed in square millimeters using standard measurement software (Leica Qwin Leica Microsystems). A reference ruler (Peak Optics, USA) was scanned with the casts to recalculate proportions. FSA data were recorded per tooth. The duplicate measurement error (DME) of this method is 0.45 mm^2. Inter-observer agreement was calculated: correlation coefficient of ≥ 0.998. The intra-observer agreement showed a correlation coefficient of 0.994 [11].

Statistical analyses

Firstly, recorded data of the casts at T_3 were compared with the data of casts at T_0 in order to calculate the increase of the FSA for each tooth (ΔFSA). Mean FSA per tooth type (incisors, canines, premolars and molars) were also calculated for T_0 and T_3. Teeth that had been restored in the observation period were excluded from the analyses.
Secondly, occlusal tooth wear resulting from attrition in one arch was expected to be related with occlusal wear in the opposing arch. To test this, a Pearson correlation test was performed to assess correlations between the increase of occlusal FSA in opposing pairs of teeth.

Thirdly, a backward regression analysis was used to assess associations between the dependent variable '(ΔFSA)' and the independent variables 'type of dynamic occlusion', 'self-reported clenching', 'self reported grinding', 'canine Angle classification', 'depth of the sagittal curve', 'horizontal overbite', 'vertical overbite' and 'history of orthodontic treatment'. The level of significance for inclusion of parameters in the backward regression was set at p=0.10. Parameters that were found significant in the backward regression analysis were used in a multiple linear regression model. For this final model the level of significance was set at p=0.05. The multiple linear regression analysis was done for each tooth type and for the entire dentition.

Table 7.1 Descriptives of occlusal conditions of the participants at baseline (n=28).

Dynamic occlusion	Left side	Right side	Both sides
Incisal guidance	2	2	1
Canine guidance	22	19	15
Group function	4	7	1
Canine Angle classification			
Class 1	26	19	19
Class 2	2	9	2
Class 3	0	0	0
Sagittal curve depth (mm)			
Mean (SD)	2.0 (0.7)		
Range	1.0 - 4.3		
Mean anterior overbite (mm)			
Horizontal			
Mean (SD)	3.2 (1.1)		
Range	1.5 - 6.4		
Vertical			
Mean (SD)	3.3 (1.2)		
Range	0.3 - 6.6		

Results

Tooth wear assessment

Mean values for FSA per tooth and per tooth type are shown in Table 7.2 and Figure 7.1 respectively. Mean FSA ranged from 4.2 to 12.2mm^2 at T_0, and from 5.3 to 15.6mm^2 at T_3. The mean increase in FSA (ΔFSA) ranged from 1.1mm^2 for premolars and incisors to 3.4mm^2 for molars, and the *relative* increase of the FSA ranged from 15% to 23%. Highest ΔFSA (>3mm^2) was found in mandibular molars and lowest (<1mm^2) was seen in mandibular incisors. In 73 (11%) of the 662 measured teeth smaller FSA were measured at T_3 than at T_0, of which 21 exceeded the DME of 0.5 mm^2 [11].

Table 7.2 Mean measured facet surface areas (FSA) in mm² per tooth type at T_0 and T_3, difference between measurements (ΔFSA) and percentage difference.

Tooth type	FSA at T_0		FSA at T_3		ΔFSA		
	Mean (SD)	Min - Max	Mean (SD)	Min - Max	Mean (SD)	Min - Max	Mean %
Incisors	6.6 (4.0)	0.8 – 23.9	7.9 (4.3)	0.9 – 26.5	1.3 (1.3)	-0.9 – 6.6	15.2
Canines	6.2 (4.2)	0.8 – 23.0	7.7 (4.6)	0.7 – 29.0	1.5 (1.6)	-1.1 – 7.9	19.5
Premolars	4.2 (3.3)	0.2- 18.9	5.3 (4.3)	0.8 – 27.6	1.1 (1.5)	-1.0 – 13.9	22.6
Molars	12.2 (8.0)	0.5 – 43.7	15.6 (9.0)	1.7 – 48.1	3.4 (3.0)	-1.3 – 20.0	21.8
All teeth	7.6 (6.3)	0.2 – 43.7	9.5 (7.4)	0.7 – 48.1	1.9 (2.3)	-1.9 – 20.0	20.0

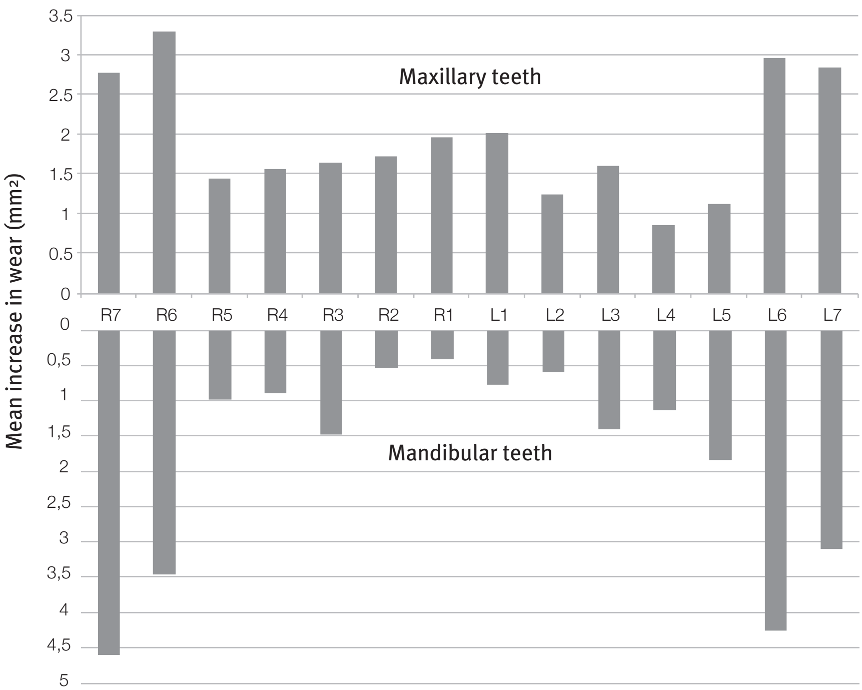

Figure 7.1 Mean increase in facet surface areas (ΔFSA) (mm²) per tooth. R7 = 2nd molar right side, R6 = 1st molar right side, etc.

Correlation coefficients for ΔFSA in opposing teeth are shown in Table 7.3. Lowest correlation (0.10) was found for incisors, indicating that the increase in FSA of maxillary and mandibular incisors did not correspond. Molars showed the highest (0.43) correlation, meaning that the increase in FSA of maxillary and mandibular molars was of the same order.

Table 7.3 Pearson correlation coefficients and P-values for ΔFSA in opposing teeth.

	Type of opposing teeth			
	Incisors	Canines	Premolars	Molars
Correlation	0.10	0.19	0.32	0.43
P-value	0.62	0.34	0.11	0.02

Tooth wear and occlusal variables

As the number of participants that had dynamic occlusion on incisors (incisal guidance) was small compared to the number of individuals that had canine protected articulation, they were combined into one group (anterior protected articulation; canines and/or incisors disengage the posterior teeth in the lateral excursive movements of the mandible). Likewise incisors and canines were combined to 'anterior teeth'. Backward regression analysis did not show significant associations of ΔFSA with the parameters

Table 7.4 Effects of included occlusal conditions and self reported grinding on ΔFSA in Anterior teeth, Premolars, Molars and All teeth in the multiple linear regression model

Occlusal condition	Anterior teeth			Premolars		
	Effect	p	95% CI	Effect	p	95% CI
Constant	2.426			4.092		
Canine Angle Class II	0.914	0.01	[0.231 ... 1.597]	0.387	0.58	[-1.020 ... 1.793]
Anterior guidance	-0.476	0.10	[-1.055 ... 0.102]	-1.466	0.02	[-2.658 ... -0.274]
Horizontal overbite	-0.355	0.03	[-0.667 ... -0.042]	-0.323	0.31	[-0.967 ... 0.321]
Self reported grinding	-0.003	0.99	[-0.542 ... 0.536]	0.631	0.25	[-0.479 ... 1.741]
R^2		0.280			0.252	

'group function', 'vertical overbite', 'depth of sagittal curve', 'history of orthodontic treatment' nor 'self-reported clenching', while 'canine Angle class II', 'anterior protected articulation'', 'horizontal overbite' and 'self reported grinding' were found significant parameters.

The final multiple linear regression model was composed using these significant parameters. Table 7.4 shows that in this model, the occlusal conditions that were significantly associated with ΔFSA were: 'canine Angle class II relation' (effect: more wear on anterior teeth), 'anterior protected articulation'' (effect: less wear on premolars and less wear in general) and 'horizontal overbite' (effect: less wear on anterior teeth with more overbite). If all teeth were combined, only 'anterior protected articulation' had a significant effect. 'Self reported grinding' was not associated with increase in FSA ($p = 0.07$).

Discussion

The role of disclusive protection of anterior protected articulation has been addressed in several cross sectional studies. Abdullah et al (1994) [7] and Johansson et al (1994) [8] found more anterior tooth wear in young adults with anterior protected articulation, but no differences in tooth wear status of the entire dentition when different occlusal guidance schemes were compared. A recent study from China also found no association between occlusal tooth wear scores and occlusal guidance scheme [16]. The present

	Molars			All teeth		
	Effect	p	95% CI	Effect	p	95% CI
	3.990			2.982		
	-0.193	0.81	[-1.824 ... 1.438]	0.393	0.33	[-0.430 ... 1.215]
	-1.227	0.08	[-2.610 ... 0.155]	-0.862	0.03	[-1.559 ... -0.165]
	-0.018	0.97	[-0.765 ... 0.729]	-0.208	0.27	[-0.584 ... 0.169]
	1.205	0.07	[-0.083 ... 2.492]	0.361	0.26	[-0.289 ... 1.010]
		0.238			0.250	

study showed a significant overall protective effect (lower ΔFSA for all teeth) of anterior protected articulation compared to group function (Table 7.4). However, when looking at the different tooth types it appears that this effect was mainly caused by premolars; since anterior teeth and molars showed no statistically significant lower ΔFSA. It is not clear why our prospective follow-up data differ from those cross sectional outcomes. Perhaps it is caused by the difference in registration methods, since the results obtained with indices are hardly comparable to measuring FSA. Where indices hamper an estimate of the surface area of the FSA, errors in the present recording process of making impressions, producing casts, marking facets, and measuring of scanned facets might also cause bias. The rarely recorded 'negative increase' was considered to be a result of such errors, however they were not excluded, as errors could be false positive as well. Nevertheless, 71% (52 out of 73) of the facets that showed decrease of FSA, were within the 0,5 mm^2 standard error of the measuring method [11]. The method used in the present study has been found accurate and reproducible, but has not yet been calibrated with three-dimensional systems. Conclusions from studies that calibrate two-dimensional wear assessment and three-dimensional wear assessment are unfortunately not applicable as most of the two-dimensional methods use step-height differences [17]. Our semi two-dimensional method has a shortcoming in measuring wear of incisors. If mandibular incisors wear vertically from the incisal, they will initially show a completely worn incisal surface. Further increase of the incisal wear facet by vertical loss of tooth substance can hardly be measured by our method since the circumference of the facets on mandibular incisor will show almost no increase, due to the anatomy of the teeth.

We expected that ΔFSA in antagonistic pairs was correlated, but this was not the case for all types of teeth: a significant correlation was found for molars but was absent for anterior teeth. This can be explained by the measurement technique: mandibular anterior teeth have different inclinations towards the plane of the scanning table compared to maxillary anterior teeth. Labial surfaces of mandibular incisors could be 'out of sight', or registered under an angle with the scanning table, and could thus be measured smaller than actually is the case. We cannot explain the absence of correlation between antagonistic premolars.

In a twenty-year follow up study on incisal tooth wear, increased incisal tooth wear was associated with increased horizontal overbite (4.1mm) [18]. The participants in that study that had less overbite showed a substantial lower amount of incisal tooth tissue loss (horizontal overbite 2.9mm). In contrast, in our study horizontal overbite was negatively correlated with tooth wear progression on anterior teeth. A recent study investigating relationships between tooth wear and previous orthodontic treatment showed no significant effects of horizontal overbite on incisal tooth wear [19]. Silness et al (1993) [20] found complex relations between horizontal overbite and increase in incisal wear. Outcomes from studies on the relationship between horizontal overbite and anterior tooth wear therefore remain inconclusive.

It was expected to find only minimal increase of occlusal wear on anterior teeth in individuals with canine Angle class II occlusions since the incisors may not be in contact with this type of occlusion. However the present study shows significant changes in wear facet surface areas. This might be explained by the wear of the canines, as incisors and canines were combined into one group in the analysis. We reexamined the casts and found that in all but 4 cases there were contacts between upper and lower incisors were present in intercuspal position. All of these four cases had a canine Angle class I relationship. The term *canine Angle class* therefore only gives information about the canine relationship, and does not provide information about contacting incisors. A study on functional contacts and static occlusion confirms that no significant association was noted between the type of lateral guidance and the canine or Molar relationship [21]. Therefore the effect of canine Angle class II on anterior teeth that was found significant in the analysis, must be interpreted with caution, and our conclusions do not include statements about canine Angle classification.

However, for deep bite occlusions (increased vertical overbite), as in Angle class II relations, Bauer et al (1997) concluded that the steepness of incisors plays a major role in the progression of anterior tooth wear [22]. The finding that steep inclined incisors show more tooth wear also suggests that recording of the inclination of incisors may be useful in future studies on incisal wear [23]. Oltravari-Navarro et al (2010) showed that an Angle class II division 2 condition was associated with more wear on labial surfaces of mandibular incisors, but not necessarily with more tooth wear in general [24]. Janson et al (2010) found more wear of incisors in subjects with Angle class II division 1, although maxillary and mandibular incisors may have minimal contact in these cases [25]. To record this type of wear better, the labial surfaces need to be examined too and not only the occlusal and incisal surfaces as in our study.

Conclusions

Regarding increase of facet surface areas (FSA) in this convenient sample, we conclude that:

- increase of anterior FSA was negatively associated with horizontal overbite ,
- increase of occlusal FSA was negatively associated with anterior guidance
- increase of occlusal FSA was not associated with self reported grinding.

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8

An experimental investigation into dental wear: tooth-tooth contact

Masen MA, Van 't Spijker A, Kreulen CM. **An experimental investigation into dental wear: Tooth-tooth contact.** *Proceedings of the Institution of Mechanical Engineers, Part J: Journal of Engineering Tribology* 2010, Vol 224, Issue 6, pp. 589 – 594.

Abstract

This work discusses some experiments with respect to the sliding contact between human teeth. The objective is to study if in-depth investigations into the dominant wear modes in dental wear can be made using a standard tribotester with samples manufactured from natural teeth. A tribological pair of two test samples was prepared from each single incisor by cutting it into halves and machining one half to be flat and the other to be hemispherically shaped.

Sphere-on-flat reciprocating sliding contact experiments were conducted. The resulting wear track was analysed and the wear volumes were quantified. The observed variation in wear volumes was larger than what would be expected as inherent to the wear process, which is attributed to biological variations and the resulting variations in mechanical properties of the used specimens. For in-depth studies of the basic mechanisms involved in dental wear, the samples should receive special care and attention, particularly with respect to enamel thickness and prism orientation. The obtained results indicate that two wear regimes are predominant and that their occurrence might be related to the thickness of the enamel layer that covers the teeth.

Introduction

Wear of human teeth is a considerable problem in society. It can lead to limitations in oral function and has an irreversible character. Because of its multi-factorial nature, it cannot be explained, prevented or treated in a simple way. Although the problem of tooth wear is often encountered in clinical practice, the basic mechanisms are presently not fully understood, see for instance Mair and Zhou and Zheng [1,2].

Published studies on dental wear can be divided into two groups: works that focus on artificial or restorative dental materials and those that focus on natural teeth. The majority of studies in the latter group focus on the aetiology of tooth wear and study the results of wear processes to teeth as observed by dentists in clinical practice. Literature on the in-vitro wear behaviour of human teeth material usually involves a contact pair composed of one human teeth and a ‘foreign body’, such as restorative materials [3] or a tribologically well defined material, such as stainless steel or titanium [4,5,6]. Only few studies have been found that describe wear tests on a tribological system related to attrition, i.e. the tooth-tooth or enamel-enamel contact pair. Kaidonis *et al* performed tests with premolar and molar teeth which were cut in half to obtain the required two contact partners [7]. The crown parts of the teeth were brought in contact under a load of 31.8 N (3.2 kgf). It was found that dental materials show the same kind of wear behaviour as that observed in ‘traditional’ engineering materials; i.e. initially a severe running-in process takes place, followed by a mild(er) steady state wear regime. Kaidonis and co-workers also studied the influence of load, acidity and sliding velocity. A concise review of the work of Kaidonis and a few other studies on enamel contact pairs is given by Lewis and Dwyer-Joyce [8]. Recently, Zhou and Zheng published an extensive review on the tribology of dental materials, in which they confirmed an earlier observation of Mair that due to the focus on aetiology and studies to rank the performance of artificial dental materials, there still is a lack of understanding of the basic mechanisms of oral tribology [1,2].

A study of wear mechanisms of dental materials including bovine enamel was done by De Gee and co-workers using the ACTA wear machine [9]. However, since bovine enamel and human enamel can differ in material properties, see for instance Esser *et al*, the question remains if such a set-up allows a good comparison to the process of tooth wear in human enamel [10].

The current work is intended as an initial step towards the understanding of the basic mechanisms of oral tribology. The objective is to study if in-depth investigations into the dominant wear modes in dental wear can be made using a standard tribotester with samples manufactured from natural teeth. The rather complex oral tribological system is simplified: two enamel samples with controlled geometries are created from a single incisor and brought into reciprocating sliding contact. After the sliding test the resulting wear track is analysed.

Methods and Materials

The experimental set-up should operate under conditions that are as similar as possible to the actual tribological test system of tooth-tooth contact that occurs in attrition. The choice of test system is a trade-off between complexity, controllability and direct applicability. In tribological testing, the preferred geometry of the tribo-pair is a ball against flat, as this eliminates stress peaks due to misalignments of the two contact partners. The use of such a relatively simple contact pair also enables the use of Hertz elastic contact theory to estimate the pressure, elastic deformation and the contact dimensions as a function of the load, assuming the materials to be isotropic, homogeneous and assuming the enamel to be sufficiently thick, i.e. ignoring the dentine material under the enamel [11,12].

For the elastic contact between a spherical body and a flat counter body, the mean Hertz contact pressure pa can be calculated from:

$$p_{\mathrm{a}} = \left(\frac{F \cdot E'^{2}}{9 \cdot \pi^{3} \cdot R'^{2}} \right)^{\frac{1}{3}} \tag{1}$$

In which F is the normal load, and E' and R' respectively the reduced Young's modulus and the reduced radius of the tribo-pair as defined below, with indices 1 and 2 referring to the two contacting bodies:

$$E' = 2 \cdot \left(\frac{1-\nu_1^2}{E_1} + \frac{1-\nu_2^2}{E_2} \right)^{-1} \tag{2}$$

and

$$R' = \frac{1}{2} \cdot \left(\frac{1}{R_{1,x}} + \frac{1}{R_{1,y}} + \frac{1}{R_{2,x}} + \frac{1}{R_{2,y}} \right)^{-1} \tag{3}$$

The used experimental set-up consists of a stationary head and a translating table, as illustrated in Figure 1 and is discussed in more detail by Faraon [13]. This system is designed to make a repeated reciprocating sliding movement at a constant steady state velocity and a constant and for engineering tribology applications rather low load. The part of the trajectory where the sample accelerates or decelerates around the turning point of the reciprocating motion is limited.

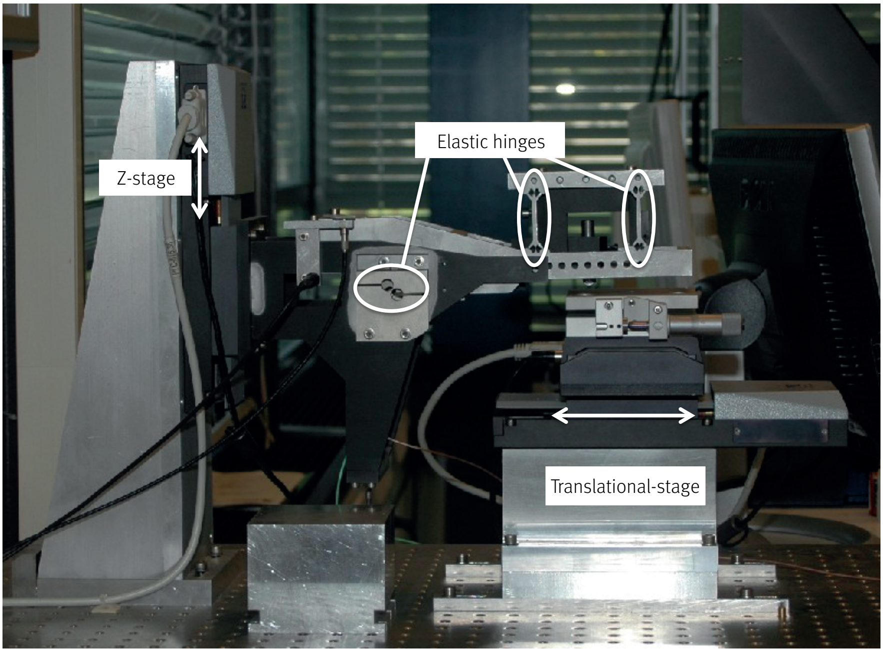


Figure 8.1 Overview of the experimental set-up.

Sample preparation

Nine incisors that were extracted from patients by their dentist for a variety of dental health reasons were collected. Only intact sound teeth without suspicious discolorations were used after selection by a dentist. No further information on the donors was recorded. Teeth were kept under water at room temperature upon specimen preparation. Both contact pairs, the ball and the flat surface, were manufactured from one and the same human tooth, as illustrated in Figure 2. Therefore nine contact pairs (i.e. a flat surface and a ball) were available for testing. The dimensions of the flat test samples were restricted by the sizes of the extracted teeth. The flat surface was subsequently polished using 1200 grit waterproof sandpaper, resulting in a surface roughness Rq of 0.03 – 0.05 µm. The ball specimens were produced by panthograph milling (Celay ®, see Figure 3) using a steel ball with a diameter of 2 mm as the master shape. These samples were polished with 0.5 micron diamond paste. Subsequently, all samples were cleaned in an ultrasonic bath using demineralised water and visually inspected under a microscope for roundness, smoothness, colour (enamel or dentine) and any embedded particles remaining from the polishing process. Figure 4 shows a photograph of two samples in contact.

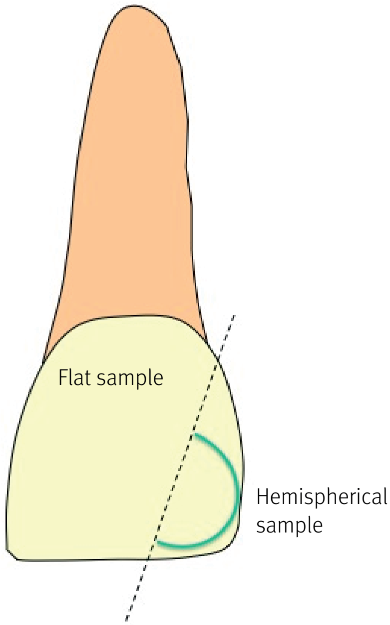


Figure 8.2 Creating the tribological pair from one incisor.

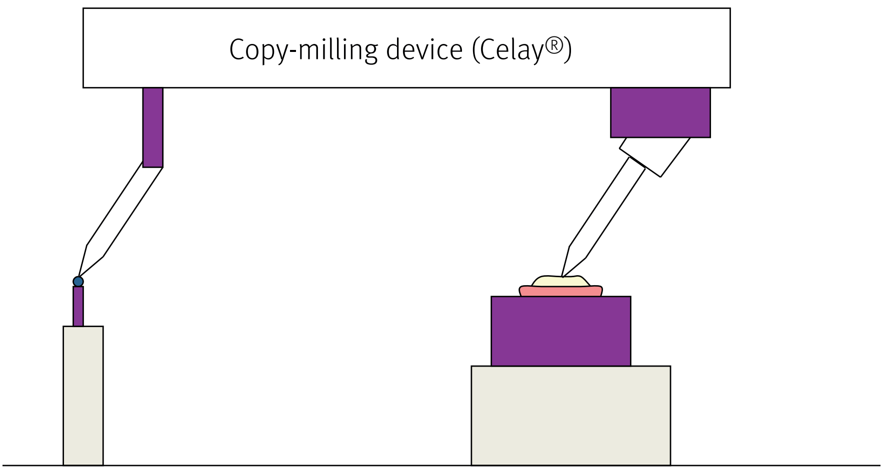


Figure 8.3 Schematic of the Copy-milling device (Celay®).

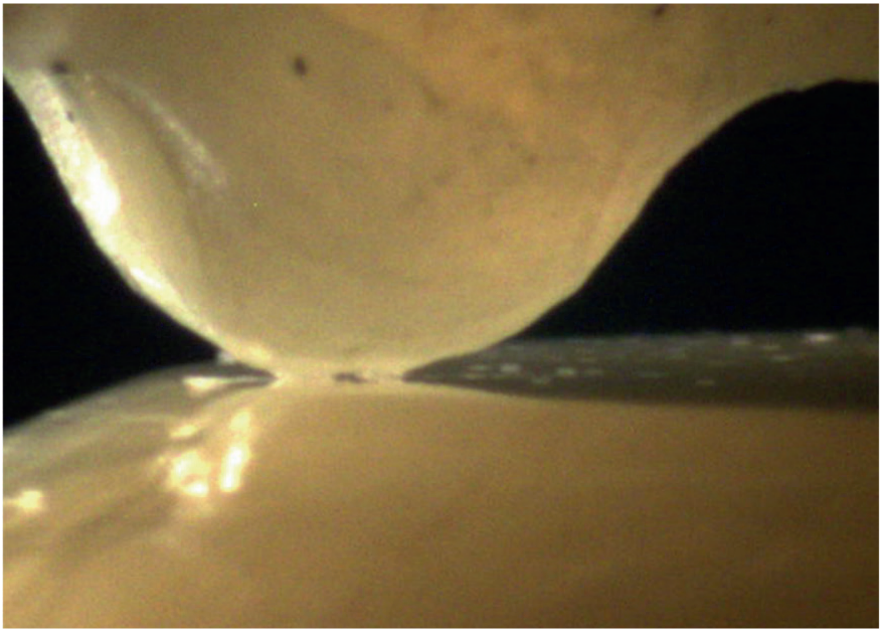


Figure 8.4 Photograph of the two samples in contact.

As there are no non-destructive methods to determine the orientation of the enamel prisms before the test was executed, this could not be taken into account. The direction of motion was parallel to the length-axis of the tooth, this orientation was controlled visually.

To provide a reference point as well as a control that the experimental set-up was able to produce repeatable results under the applied operating conditions, three 100Cr6 steel tribo- pairs with similar dimensions were also included in the test programme.

Test conditions

Estimations for biting loads vary from 3 to 900 N depending on the location (front teeth or molars) and the system that is used for the measurement (measuring devices between teeth, transducers in restorations or transducers in dentures at the level of the gingival) [16,19,20]. Also, total contact areas vary per tooth type; molars have larger contact areas than front teeth. These wide ranges mean that the contact pressures are ranging over several orders of magnitude.

Also, a wide range of values is reported for the mechanical properties for enamel, see e.g. Spears, who mentions Young's moduli ranging between 20 GPa and 84 GPa [14]. Recent literature tends towards the higher values in this range. In accordance with

Barink *et al* and Lewis *et al*, a Young's modulus E = 84.1 GPa and a Poisson ratio of $\nu = 0.30$ was used in the current work [8,15]. Substituting these values into equation (2) above gives E' = 92.4 GPa. Inserting the geometry of the samples $R_{1,x} = R_{1,y} = 1.0$ mm and $R_{2,x} = R_{2,y} = \infty$ (flat surface) gives a reduced radius R' = 0.5mm and therefore a load of 1 N results in a mean Hertzian contact pressure p_a = 497 MPa.

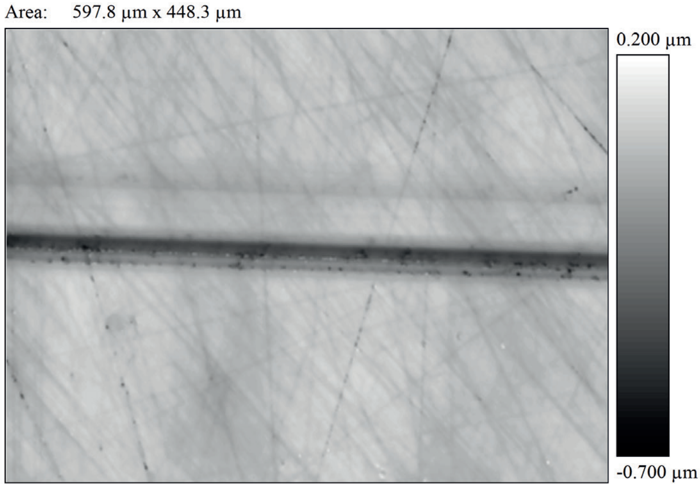
In a preparatory set of experiments, teeth tribo-pairs were tested under only 25 cycles, with further identical conditions. On some samples a small wear track could be observed, in most teeth no wear could be measured. Unfortunately, the current set-up does not enable in-situ wear analysis, nor is it possible to pause an experiment and take one or both of the samples out to analyse the amount of wear, as accurate repositioning of the sample can not be guaranteed. Therefore in the current tests the number of cycles was chosen high: 5000 cycles, equivalent to a sliding distance of 30 metres, reflecting in vivo values during chewing [16,17,18]. The experimental conditions are listed in Table 1.

Table 8.1 The experimental conditions

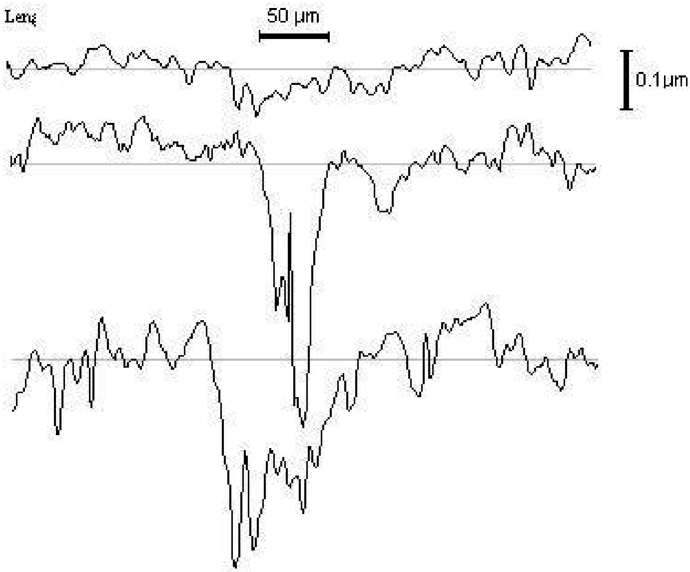
Contact geometry	sphere on flat
Contact mode	dry sliding
Diameter of hemispherical sample	2 mm
Load	1 N
Mean Contact Pressure (Hertz)	500 MPa
Movement	reciprocating
Speed	1mm/s
Stroke length	3mm
Number of cycles	5000
Sliding distance total test	30 m

Results

After the sliding experiment, a clear track could be observed by the naked eye in all nine cases. Inspection under a microscope revealed that the wear tracks on seven samples had a topography similar to the ones shown in Figure 5. The other two surfaces showed tracks that considerably differed: in one of the two differing samples no enamel layer was absent on the spherical surface, and in the other sample the scar in the flat surface passed the enamel layer.



A



B

Figure 8.5 A. Wear morphology. B. Profilometry plots across the wear tracks on three of the specimens.

The wear tracks on the remaining seven tooth surfaces were measured using an interference microscope. The wear morphology is shown in Figure 5(a) and (b); Figure 5(a) shows a 2d surface plot and the dark band indicates the wear track. The profile plots of Figure 5(b) show profiles across the wear tracks as measured on three of the specimens. All observed wear tracks do have straight boundaries and therefore the volume of the worn material can be calculated from the measured width and depth of each of the measured tracks and the length of the stroke. The results are shown as the black bars in Figure 6. A typical wear track had a width of about 50 µm and a depth in the order of 0.5 µm, although large variations were observed: it can be seen that wear volumes between 7.3·10-6 mm3 and 1.1·10-4 mm3 were obtained. The steel samples, (the grey bars in Figure 6) show significantly higher wear volumes than the dental materials, but the variation in wear volumes between the three tested steel tribo-pairs is small.

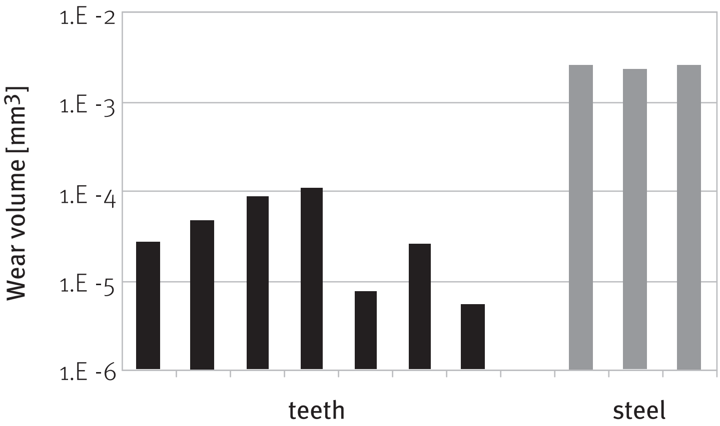


Figure 8.6 Volumetric wear per sample, black bars: dental samples, grey bars on the right hand side: results of control experiments performed with 100Cr6 samples, test conditions as given in Table 1.

Discussion

As dentine has a lower mineral component it is significantly softer than enamel and the dentine will be more susceptible to abrasive wear. The two differing samples are contributed to the fact that in both of these tested pairs the enamel layer was removed completely during the experiment and the resulting contact was one of enamel against dentine. In one instance this happened on the flat surface, resulting in a wear scar that was several orders of magnitude larger than the other wear scars, and too large to measure with the interference microscope. In the second case the enamel layer of the spherical shaped sample was worn, resulting in a dentine layer that was smeared out over the initial wear scar, making it also impossible to measure.

The observed large variation in wear volumes for the dental materials can have a range of causes. The observed small variations in wear volumes for the steel samples seem to rule out any influences of the experimental set-up. Dental material is not homogeneous and does not have constant properties. For the tested samples, Vickers 100 hardness values ranging from 1913 to 3983 MPa were measured, see Table 2.

Table 8.2 Wear results expressed in Specific Wear Rate *k* and Wear Coefficient *K*

Sample	Wear Volume [10^{-6} mm^3]	Wear rate k [10^{-6} mm^3/ N·m]	Hardness HV100 [MPa]	$K = k \cdot H$ [-]
1	27.4	0.91	3384	0.0031
2	44.7	1.49	2389	0.0036
3	85.7	2.86	1913	0.0056
4			3649	
5	107	3.58	3953	0.0144
6	7.32	0.24	3983	0.0010
7			3178	
8	25.2	0.84	3983	0.0034
9	5.31	0.18	3424	0.0006

Figure 7 shows the wear rate *k* as a function of the hardness H of the samples. There does not seem to be clear relation between hardness values and volumetric wear. However, when the single result in the top right hand corner of the figure is considered to be an outlier, one can distinguish some two clusters; one in the upper left corner and one in the lower right corner, which could indicate two different wear modes. To confirm this, tests with an increased number of specimens should be performed. A possible explanation for these two modes is the layered structure of dental materials:

from an engineering perspective, a tooth can be viewed as a soft dentine substrate covered with a hard enamel surface layer. The enamel surface layer typically has a thickness in the order of 1.5 mm [21], but this can vary between subjects, between teeth and also between locations of the same tooth.

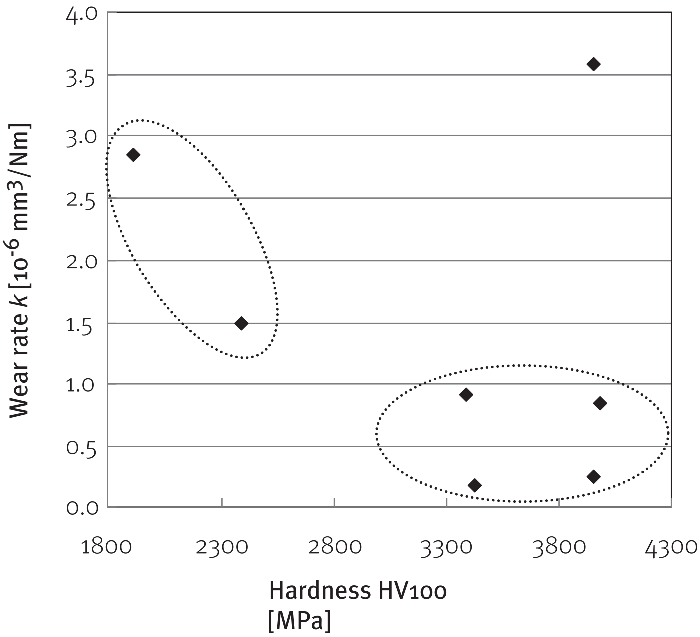


Figure 8.7 Wear rate *k* against hardness H for the tested specimens.

Based on analytical and numerical results, Michler and Blank have proposed equations and a general failure map for coated materials that defines three possible regimes: elastic deformation, plastic deformation of the substrate, and failure of the coating[22]. Figure 8 is obtained by inserting the mechanical properties of dentine and enamel in the equations given in [22]. From the figure it can be seen that regime in which the contact operates depending on the thickness of the enamel and the applied load. The hatched area marks the testing conditions as applied in the present work. Depending on the enamel thickness, the predominant contact regime changes from elastic deformation to plastic deformation of the dentine, and this will have an influence on the dominant wear mode.

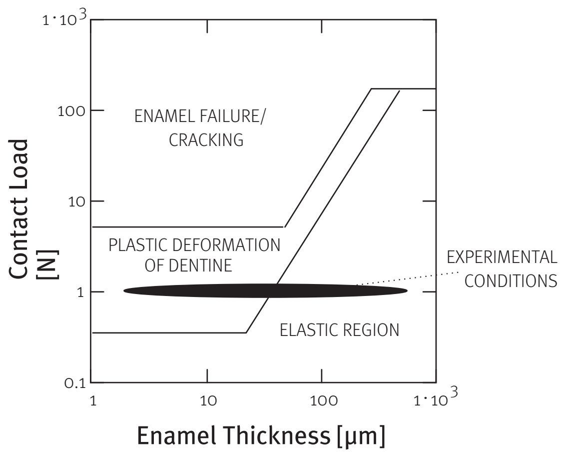


Figure 8.8 Failure map for Dental Materials, based on Michler and Blank [22].

It should also be taken into account that enamel is prismatic; the orientation of the hydroxy- apatite prisms can vary per specimen and per surface area. Since the dentine layer under the enamel is not prismatic and the thickness of both layers cannot be determined a priori, it is difficult to predict or determine how the combination of the two materials will behave. Unfortunately, analysis of the orientation of the prisms requires making a cross-section of the surface or a SEM analysis using a sputtered sample. Hence this would destroy the sample for further tribological testing.

Conclusion

The observed variation in wear volumes is larger than what would be expected as inherent to the wear process, e.g. comparative tests under the same conditions using three steel tribo-pairs showed excellent repeatability. The examination of basic mechanisms for dental wear in an in-vitro set up is difficult, despite a precisely controlled tribological test-setup. Biological variations and therefore the (mechanical) properties of the used specimens cannot always be controlled and seem to have a significant influence.

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9

General discussion

General Discussion

This discussion addresses the seven chapters of this thesis, and aims to relate the findings and problems encountered in the studies to the later research findings. The remaining questions on the topic of the aetiology and assessment of tooth wear are put forward and recommendations are given for future research. The prevalence of tooth wear is the first subject to be discussed, followed by the assessment methods and aspects of tooth wear and occlusion. Clinical implications and recommendations for dental practitioners and future research are outlined, and finally overall conclusions are presented.-

Prevalence of tooth wear

Literature search, inclusion exclusion

To gain more insight in the prevalence of tooth wear, a review was conducted, starting with a PubMed search. The assignment of keywords is the well-considered choice of the authors to obtain a wealthy source of references, which was determined by the listed keywords and Mesh-terms in PubMed. To increase the number of hits, keywords with a wider spectrum could be used or keywords of which the definition has evolved. Despite our approach, an electronic search will always be biased. The number of hits of our electronic search was very high which made a manual selection almost undoable. In our view, calibration of the selectors was essential which was checked by inter-examiners agreement. A recent paper illustrated that the use of only electronic searche engines, will result in finding maximally 87% of the papers that could potentially be found [1A]. Our search strategy also proved to be valuably complemented by the reference lists of included papers. From published reviews nowadays, it appears that the manual selection is mostly done by one operator and selection of papers relies for the majority on a selective search strategy, by which information might be missed.

Tooth Wear Index

The main issue in prevalence studies on tooth wear is the classification of the registrered tissue loss. Indices are the only way to record the tooth wear status of large numbers of subjects in a limited observation period. Definitions of types of tooth wear appear to evolve. For instance, loss of tooth substance on the buccal aspects of teeth have been described as erosion in the 1980's but might be determined as abrasion today. We concluded that data presentation using a 'skeleton index' and if necessary, a modification that fits the aims of the study, enables comparison with data of other studies. Salas *et al* recently confirmed this [1].

The reviews in Chapters 2 and 3 chose to recalculate prevalence data according to the Smith and Knight index, because most of the included studies used this index or a modification. That does not make this index the most suitable to be applied in prevalence studies. The index is not sensitive enough to record changes in early stages of tooth wear that are limited to enamel. This scale roughness of the Smith and Knight index originates from the fact that it was also used as a threshold to start restorative treatment once dentine was involved, and this index has established to be a kind of multi-purpose measuring tool. Although some authors have questioned whether the determination of dentine exposition is unambiguous, still the majority of indices used today have the dentine exposition as cut-off point between two stages in the index [3,4,5].

Assessment of prevalence data

The dichotomy of dentine exposition in deciduous teeth makes it difficult to compare these results to the permanent dentition, as tooth wear in the permanent dentition is often graded using a five-point scale. Therefore assessment of tooth wear on both deciduous and permanent teeth should be executed separately. Additionally, the prevalence data of adults show less variation in comparison to the data concerning children. Although we used the skeleton index, larger variations in size of the included studies, study design, the use of partial or full mouth recordings, the presence of a mixed dentition and the type of index made it difficult to compare prevalence data from the studies on children and adolescents or construct a regression model to analyse the relation between tooth wear and age.

The aim of the studies in Chapters 2 and 3 was to combine the results of consistently executed cross-sectional studies to answer the question whether the prevalence of tooth wear has actually increased during the last decades. Regarding the results of Chapters 2 and 3, it remains unclear whether the prevalence of tooth wear is increasing. This is best illustrated by the forest plot in Chapter 3. As expected, teeth will wear during ageing (due to mechanical function) which is depicted in figures 2.2 and 2.3 by the increase of severe wear with age. Both figures show that the more recent studies do not necessarily find higher percentages of subjects with severe wear.

It would be best to compare prevalence data from studies preformed in the same geographical region with a certain time interval. However, from the studies that were included in Chapters 2 and 3, but also by analyzing prevalence studies published after 2007, only four studies compared results with prior comparable investigations [6,7,8,9]. Of the four studies, two found no increase and two did find an increase of tooth wear related to time. We performed a quick scan of prevalence studies published after 2007, and found 17 studies presenting prevalence data; the results were in line with our findings (3,3% of young adults showing severe stages of tooth wear [10]) and also the correlation between tooth wear and age that was confirmed. Therefore we conlude that the data presented in the two reviews is still current.

In comparing data, reviewers should be aware of the fact that the reported prevalence depends on the geographic location and the use of different indices [2,10]. A review article on the development of dental erosion shows a variety of prevalence data ranging from 1% to 77% [11]. When ordering the included studies geographically and subsequently chronologically, no increase of prevalence can be concluded [2]. Remarkably, the review by Salas *et al* showed that studies published after 2010 found a lower mean prevalence of tooth wear compared to studies published before 2010. In this light it is also remarkable to find that the opening statement in a recent review paper on the treatment of tooth wear does not state '*The prevalence of tooth wear is increasing*' but instead '... *perceived as an increasing problem*' [12].

The role of occlusion in tooth wear

Canine guidance versus group function

The most common natural human articulation type and its possible relation to dysfunction of the oral system has been reason for discussion among dental professionals during the last century [13]. From restorative perspective canine guidance has often been preferred for its assumed protective nature, which is in line with the expectation that tooth wear will be minimal if this type of dynamic occlusion is present in an individual [14,15]. Some authors suggest that (dynamic) occlusion and occlusal relations need to be altered to canine guidance in order to manage the progression of tooth wear [16,17]. However, the studies in the systematic review in Chapter 4 failed to find sound evidence for recommending a certain occlusion-based treatment protocol above another in the management of attrition. This view is supported by the results of another, more recent systematic review on the relations of occlusion, patient comfort and restoration longevity [18]. A recent consensus-report on the treatment of erosive tooth wear (ETW) states: '*There is no evidence that ETW should be treated differently from established procedures; loss of tooth tissue should be restored according to the site and extent of loss, regardless of the cause.*' [19].

By definition attrition is caused by friction. The common assumption that clenching or grinding may be induced by malocclusion, might lead to the idea that the (mal)occlusion not only causes tooth wear, but also temporomandibular dysfunction (TMD). In a recent review it is concluded that there is no evidence for a causal relationship between 'the bite' and bruxism [20]. The causes of grinding and clenching are more likely to be found in psychological and behavioural conditions than in the occlusal conditions. This, together with the finding that attrition seems to be co-existent with self-reported bruxism, leads to the conclusion that dental occlusion, bruxism, TMD and tooth wear have a complex -but not causal- relationship, which is too complex to be explained by the results of a single cross sectional study.

The assumption that absent posterior support leads to increased attrition of the remaining teeth seems reasonable. Various reports indicate that this cause and effect relation is not proven [21]. One included study reported that fewer number of teeth resulted in more tooth wear on the remaining premolars, which was confirmed by a more recent study [22,23]. Likewise individuals with fewer numbers of posterior occlusal pairs were associated with more wear in anterior teeth, since the anterior teeth are more involved in the chewing process as posteriors are missing.

Occlusion assessment and aspects

Although literature did not indicate a relation between occlusion and tooth wear, the mainstream of the profession is convinced that the concept of canine guidance should be implemented in cases where extensive restorative treatment is indicated. In order to investigate the relation between dynamic occlusion and tooth wear, it is essential to determine which type of dynamic occlusion a patient has. Dental clinicians and technicians indicate that the type of dynamic occlusion can be determined by the presence of wear facets. In a pilot study on the matching of study models, we experienced that the presence, shape and location of occlusal wear facets on study models was not enough to reach consensus in determining the type of dynamic occlusion, more specific the lateral occlusion scheme.

Clinical assessment of the dynamic occlusion is often done using shim stock foil of 12 µm thickness. The accuracy of ultrathin foil between contacting teeth is evident, but the articulation pattern of the patient, depends on the position of the head and body. The present / actual dynamic occlusion approximates the movements by guidance of the mandible to the border movements, with the patient's Frankfort plane in a horizontal position. This appeared to be a common method of examination of the dynamic occlusion [24]. We did not find studies on body position influencing occlusal contacts. However, most dentists will confirm the common clinical finding that after finishing an occlusal restoration with the patient lying in a horizontal position, different occlusal contacts are experienced when the patient changes sitting into the up-right position. Both researchers and general practitioners should be aware that the type of dynamic occlusion is dependant of factors such as head posture and body position and incorporate this in research design respectively treatment setting.

Measuring wear

One of the conclusions of Chapter 4 was, that no papers were found-reporting threshold values of attrition indicating whether intervention might be beneficial for a patient. A recent consensus report summarizes (mainly subjective) reasons to start restorative treatment [25]. The flowchart from another recent paper, indicating different strategies and techniques in the management of tooth wear, makes a crucial distinction between pathological and physiological tooth wear, underlining the fact that dentists need to be able to detect progression of tooth wear [26]. A complicating factor is that tooth wear may be cyclical and can be inactive in the majority of the patients, despite obvious wear facets in their dentitions [27].

Already 30 years ago 3D systems like holography and stereo photogrammetry were developed as measuring tools for wear of restorations on dental models [28]. All the described systems were research applications, not suitable to be used for direct tooth wear recordings in the mouth. Until now such a system is not available. In the years we designed our measuring studies, we made use of a laboratory laser scanner and gypsum casts. The software at that time was in an early state, making it nearly undoable to record and measure large numbers of study models.

In the search for a simple registration technique we developed the procedure using a flatbed scanner as described in Chapters 6 and 7. The outcomes of this 2D system are difficult to interpret, and with all of its advantages and disadvantages, we regarded this to be one of the temporary tests to measure tooth wear. Although intra-oral scanners have evolved ever since, suitable software to calculate still has to be introduced on the market. The puzzle with this kind of data is the choice of reference points and the process of subtraction of data. By scanning models or making intra-oral scans, each point has X, Y, and Z values. It is not guaranteed that a second scan registers the same point on the surface of the tooth, therefore subtraction of the two datasets does not guarantee to depict the actual difference between the two models. Moreover, superimposing two scans of a recorded complete dental arch with a time interval hampers reliable reference points or surfaces due to tooth migration.

Assessment of tooth wear

Wear assessment

Although our developed 2D measuring method seemed reproducible on itself, one could argue that monitoring changes of surfaces that are not parallel to the scanner surface is not possible at all. Actually, we encountered difficulties measuring the wear on incisors but did not find an explanation. The method is charming in its simplicity and easily available for every practitioner. Additionally, most of the individuals we followed showed attrition as the most important cause of wear. As a consequence it is expected that opposing teeth show comparable amounts of wear. Perhaps due to anatomical and methodological limitations we found lower progression of wear facet areas in the lower jaw than in the upper jaw. As far as we know, no published study describes information in the wear characteristics of two opposing teeth. From daily life it is recognized that two surfaces of the same material that are in gliding contact, the one surface shows more deterioration than the other. Possibly the same phenomenon occurs in tooth wear. The tribological laboratory study described in Chapter 8 also demonstrated a large variety in wear outcomes when enamel spheres were put in repetitive sliding contact with enamel planes. In that study we expected differences in enamel thickness and prism orientation to be the explanation of the observed variation in wear volumes as the stiffness of enamel is smaller in the direction normal to the main axis of the prism, but such relationship has not been analysed yet [29]. From an engineering point of view a tribological model will be less consistent when the normal range of differences in mechanical properties of dentine and enamel are added to differences in enamel thickness and prism orientation. This may also be an explanation for the results presented in Chapter 7, where differences in tooth wear of opposing premolars were found (Figure 7.1).

In Chapter 6, the backward regression analysis did not show significant associations of increased facet surfaces areas with the parameters 'group function', 'vertical overbite', 'depth of sagittal curve', 'history of orthodontic treatment' nor 'self-reported clenching'. On the other hand 'Canine Angle class II', 'anterior protected articulation', 'horizontal overbite' and 'self reported grinding' were found to be significant parameters. The choice of these parameters was mainly determined by the outcome of the occlusal factors studied and described in the review in Chapter 4. The parameters Angle class II and horizontal overbite both indicate spatial relationships describing the anatomical situation in which it is not expected anterior teeth to have occlusal contacts.

It could be argued that the number of participants in this pilot study is limited, but in a recent review on longitudinal tooth wear studies by Abduo *et al*, only seven out of 26 studies consisted of more than 30 participants [18]. Most studies tend to present clustered case reports retrospectively. Prospective studies on the role of occlusion on the progression of tooth wear and survival of restorations are scarce. Therefore conclusions cannot be extrapolated, and conclusions about the role of occlusion in tooth wear are limited.

Clinical Implications and Recommendations

General practitioners and scientists may have different interests: practitioners tend to search for evidence in treatment planning and scientists are merely questioning the validity of findings. Perhaps this explains the differences in back up for statements made in case reports compared to the studies and reviews that seem to question paradigms more and more. Being academic trained individuals, it is the general practitioner's responsibility to search for the best relevant evidence. Scientists should assist them in providing evidence through applicable research or clear reviews.

Tooth wear is a phenomenon of recent interest. Having scrutinized the literature we have only limited information that it is a generally increasing problem in the population.

Increased awareness amongst professionals, combined with increased prevalence of the more severe stages of tooth wear might explain the growing number of publications and concern amongst dentists. An interesting fact in the Netherlands is that the mean age at which complete dentures were indicated increased from 60 in 1970 to 70 in 2010. Elder people will therefore show more tooth wear, as they maintain their natural, though worn, dentition longer nowadays.

Another problem is to register when tooth wear actually develops from physiological to pathological. Actually, there is no common agreement on this transition. In an attempt to have guidelines for general practitioners a recent consensus report lists reasons to start intervention [25]. The authors state that apart from the worries about the condition and life expectancy of the patient and the dentition, also sensitivity and/or pain, difficulties with chewing and eating, impaired orofacial esthetics and “crumbling” of dental hard tissue and restorations are reasons to start treatment. Dentists in general practice may recognize primary factors and secondary factors in the decision to start treatment. Primary factors include the amount of tooth wear (grading), the affected surfaces (involved in occlusion/articulation or not) and the number of teeth affected (localized or generalized). Secondary factors include the progression (speed) of tooth surface loss, the age of the patient and the assumed aetiological factors.

There are several systems for the recording or measurement of tooth wear [30]. Depending on the purpose of the investigation, one system might prove to be more suitable than the other. Surface matching software combined with the use of 3-D systems need to be further developed in order to assess tooth wear accurately and reproducibly. The supposed preference to 3-D methods compared to 2-D, is a point of discussion, and for clinical use, general practitioners should consider visual examination of study models [30]. For occlusion registration the accuracy of shim stock foil on itself is not questioned, but today more sophisticated and perhaps more objective systems to record occlusal contacts are available, for example the T-scan system [31]. It may be useful and interesting to compare T-scan outcomes with the shim-stock outcomes, and implement these in future research.

Conclusions

- The prevalence of severe tooth wear is increasing during life, ranging from about 3% at age 20 to 17% at age 70. A strong correlation with age was found.
- There is no indication that prevalence of tooth wear has globally increased during the last decades.
- The role of occlusion in the process of tooth wear is limited, since no evidence was found justifying the qualification of certain occlusion-based interventions above others in the management of attrition.

- Body position is of influence in measuring tooth contacts during dynamic occlusion.
- Measurement of tooth wear using a 2-D method can be done precisely and accurately.
- In the convenient sample of young adults described in this thesis, anterior protected articulation and horizontal overbite had an effect on the progression of occlusal tooth wear.

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10

Abstract (English)

Samenvatting (Nederlands)

Introduction

In Western countries the caries epidemic decreased during the last decades and more and more individuals tend to retain their natural dentition. Meanwhile the non-bacterial deterioration of tooth tissues by wear caught the attention of the dental profession in this part of the world. Therefore the question arises whether the prevalence of tooth wear has actually increased in the last decades.

In the description of tooth wear three different types are differentiated. *Dental erosion* has been defined as loss of dental hard materials caused by a chemical process that does not involve bacteria. *Dental abrasion* is defined as the loss of tooth substance due to friction with a foreign body (e.g. tooth brush), and *dental attrition* is the loss of tooth substance due to friction of opposing teeth.

The amount of tooth wear varies and will increase with age. The severity of tooth wear can be assessed using a *tooth wear index*. Several indices are available, each using a scale that describes the different stages of tooth wear (qualitatively). Apart from indices, tooth wear is also measured quantitatively. Profilometry, optical techniques, and intra-oral scanners are combined with measurement and analysis software to quantify the amount of tooth wear.

Which level of tooth wear will demand intervention appears to be a difficult question, and the scientific literature does not provide an answer. Which occlusal concepts should be followed is a topic that is addressed more often, and discussion continues. An overview of the different schools on the topic of occlusal schemes since the 60's is presented, and the question is posed whether canine guidance has been proven to be a protective factor in the progression of tooth wear.

This thesis deals with the analysis of the mechanisms of tooth wear, and does not address treatment strategies. It aims to investigate the prevalence of tooth wear, in adults and in children, and to find evidence in the literature describing interaction(s) between tooth wear and occlusal factors, function or dysfunction and threshold values for intervention. Furthermore the thesis aims to investigate the progression of tooth wear, investigating three aspects: the method to determine the type of dynamic occlusion, the method to measure tooth wear (quantitatively), a laboratory model to study artificial attritional tooth wear on curved and flat surfaces and the assessment of wear facets in a convenience sample of young adults. The general discussion addresses the combined findings and compares these findings to the results published to date.

Chapter 2

The aim of this study was to investigate data on the prevalence of tooth wear in adults and assess possible correlations using a systematic review. A search of the literature, using PubMed and the Cochrane Library, from January 1980 to July 2007 was executed using keywords "tooth + wear"; "dental + attrition + prevalence"; "dental + wear + prevalence";

"erosion + prevalence"; and "abrasion + prevalence." References were independently screened for inclusion and exclusion by two investigators and Cohen's Kappa was used for agreement assessment. One hundred eighty-six references were initially selected and subjected to the systematic review procedure; 13 passed the inclusion procedure. Data were collected and converted into the Smith and Knight Tooth Wear Index.

Four articles were suitable for regression analysis at tooth level and three at subject level. Six studies reported males having significantly more tooth wear than females. It can be concluded that the predicted percentage of adults presenting severe tooth wear increases from 3% at the age of 20 years to 17% at the age of 70 years. Increasing levels of tooth wear are significantly associated with age.

Chapter 3

Analogue to the study in chapter two, the data on prevalence of tooth wear in children and adolescents and possible associations were investigated. The selection procedure resulted in 29 papers with a total of 45,186 subjects (smallest study 80 and largest study 17,047 subjects) examined from thirteen multiple random clusters, eight multiple convenience clusters and eight convenience clusters. Dentin exposure was chosen as an indicator of severe wear. Prevalence, age, gender, socio-economic status (SES), fluoride, and diet were included in the regression analyses. Assessment of mixed dentitions (deciduous and permanent teeth) was not possible, and forest plots indicated substantial heterogeneity of the included studies. Prevalence of wear involving dentin ranged from 0 to 82% for deciduous teeth in children up to 7 years; regression analysis showed age and wear to be significantly related, but not for permanent teeth in older children and adolescents. No conclusions could be drawn from the correlations with gender, SES, fluoride and diet.

Chapter 4

To gain insight in the relation between attrition and occlusal factors and masticatory function or dysfunction a systematic review of the literature was conducted on the topic with the emphasis to find evidence for occlusion-based treatment protocols for attrition. Literature was searched using PubMed (1980 to 2/2006) with the keywords 'tooth' and 'wear', revealing 1289 references, of which 33 remained after application of exclusion criteria. Two investigators independently assessed the abstracts, excluding reviews, case-reports, studies on non-human tooth material, and studies not published in English and historical or forensic studies.

Analysis of the 33 included papers failed to find sound evidence for recommending a certain occlusion-based treatment protocol regarding the management of attrition. Studies on threshold values of tooth wear were not found either. Some studies reported correlations between attrition and anterior spatial relationships. No studies were found suggesting that absent posterior support necessarily leads to increased attrition, though one study found that fewer number of teeth resulted in higher tooth wear index (on the remaining teeth). Attrition seems to be co-existent with self-reported bruxism. Reports on attrition and TMD signs and symptoms provide little understanding of the relationship between the two.

Chapter 5

This pilot study aimed to explore whether occlusal contacts during lateral excursions are influenced by different body positions. Occlusal contacts in lateral excursions were verified for 30 dental students and 22 dental staff members using articulation foil while patients were seated in a dental chair. The recorded occlusal contacts during lateral guidance were classified as group function, canine guidance or anterior guidance. The number and location of dynamic tooth contacts (initial and halfway) were registered, while the back of the dental chair was put in three positions: upright, 45 degrees, and supine. Occlusal contacts on working side and non-working side were analysed. For the majority of subjects (96%), dynamic occlusal contacts changed when the body position was altered, leading to changed classification of lateral guidance in 10 to 17% of the subjects.

Chapter 6

The aim of this study was to assess a two-dimensional method to monitor occlusal tooth wear quantitatively using a commercially available ordinary flatbed scanner. A flatbed scanner, measuring software and gypsum casts were used.

In Part I, two observers (A and B) independently traced scans of marked wear facets of ten sets of casts in two sessions (test and retest). Duplicate measurement errors (DME) were calculated. The test and retest values (10 casts, 218 teeth) of observer A and B did not differ significantly (A: $p = 0.289$; B: $p = 0.666$); correlation coefficients were 0.998 (A) and 0.999 (B). ''Tracing wear facets'' showed a DME of 0.30 mm^2 for observer A and 0.15 mm^2 for observer B. Measurement values and DME of anterior teeth did not differ from posterior teeth.

In Part II, three other sets of casts were duplicated and two observers (C and D) marked wear facets and traced the scanned images independently. Intra- and inter-observer agreement was determined comparing measured values (mm^2) in paired T-tests. Assessment of 70 teeth resulted in correlation coefficients of 0.994 for observer C and 0.997 for observer D; no differences between test and retest values were found for C ($p = 0.061$), although D differed significantly ($p = 0.000$); re-test values appeared to be higher. The DME for ''marking and tracing wear facets'' was 0.39 mm^2 (C) and 0.27 mm^2 (D).

It was concluded that marking and tracing of occlusal wear facets to assess occlusal tooth wear quantitatively using gypsum casts and a flatbed scanner can be done accurately and reproducibly.

Chapter 7

This study aimed to measure progression of tooth wear quantitatively in a convenient sample of young adults using the method (described in chapter 6) and to assess possible correlations with occlusal conditions. Twenty-eight dental students participated in a three-year follow up study on tooth wear. Visible wear facets on full arch gypsum casts were assessed using a flatbed scanner and measuring software. Occlusal conditions and anatomical parameters were recorded, and the type of dynamic occlusion was recorded as described in chapter 5. Regression analyses were used tot assess possible associations between the registered occlusal conditions 'Occlusal guidance scheme', 'vertical overbite', 'horizontal overbite', 'depth of sagittal curve', 'canine Angle class relation', 'history of orthodontic treatment', and 'self-reported grinding / clenching' (independent variables) and increase of wear facets (dependent variable).

The mean increase in facet surface areas ranged from 1.2mm² (premolars, incisors) to 3.4mm² (molars); the relative increase ranged from 15% to 23%. Increase of wear facets appeared to be larger in upper teeth than in lower, except for the molars. Backward regression analysis showed no significant relation for 'group function', 'vertical overbite', 'depth of sagittal curve', 'history of orthodontic treatment' nor 'self-reported clenching.

The final multiple linear regression model showed significant associations amongst 'anterior protected articulation' and 'horizontal overbite' and increase of facet surface areas. For all teeth combined, only 'anterior protected articulation' had a significant effect. 'Self reported grinding' did not have a significant effect ($p > 0.07$).

It was concluded that in the limitations of this convenience sample, 'anterior protected articulation' and 'horizontal overbite', were significantly associated with the progression of tooth wear. Self reported grinding was not significantly associated with progression of tooth wear.

Chapter 8

The objective was to study wear patterns using a standard tribotester with samples manufactured from natural teeth. Nine tribological pairs of two test samples were prepared from nine extracted incisors by cutting it into halves and machining one half to be flat and the other to be hemi-spherically shaped. A set of three steel specimens served as control.

Sphere-on-flat reciprocating sliding contact experiments were conducted and measurements were done using an interference-microscope. Two tribological pairs could not be analysed: in one the flat enamel layer was surpassed resulting in a wear track too deep to measure, and in one the sphere turned out to have lost all enamel resulting in a smeared dentine layer on the flat surface. Seven wear tracks could be analysed and the wear volumes were quantified, resulting in tracks with a width of 50 µm and depth of 0,5 µm. The observed variation in wear volumes was larger than what would be expected as inherent to the wear process (7,3 x 10^{-6} mm^3 tot 1,1 x 10^{-4} mm^3), which is attributed to biological variations and the resulting variations in mechanical properties of the used specimens. The tribological pairs made of steel showed deeper wear tracks but results were more consistent. For in-depth studies of the basic mechanisms involved in dental wear, the samples should receive special care and attention, particularly with respect to enamel thickness and prism orientation.

It was concluded that an in-vivo set-up to simulate attrition is difficult to standardize, due to variation in mechanical properties, such as thickness of the enamel layer and prism orientation.

Chapter 9

This chapter describes the methods and findings of the seven papers in relation to each other, discusses new evidence or questions that have risen since the research has been conducted.

In relation to the prevalence of tooth wear, it is concluded that the included studies of chapters 2 and 3 do not confirm an increased prevalence of tooth wear. The variation in reported prevalence in large, from 1 to 77%. More recent papers do not report higher prevalence. In the analysis of recent prevalence studies it should be taken into account that not only the used wear index or measuring technique, but also the country the study is performed in, can be of influence.

Correlation between tooth wear and occlusion appears not to be confirmed by results from research. However case reports tend to recommend certain occlusal concepts in the treatment of tooth wear. Application of canine guidance is recommended in case reports of reconstructive dentistry, as it is predictably achievable. The review in chapter 4, and the more recent papers cited in chapter 9, do not support the preference for canine guidance. Neither is there evidence to support the assumption, that bruxism not only causes wear, but also causes temporomandibular dysfunction (TMD). The findings of a recent review in which the relation between TMD and *the bite* is questioned, leads to the conclusion that bruxism, TMD, occlusal schemes and tooth wear have a complex, but not causal, relationship.

It seems logical to assume that loss of teeth can result in more tooth wear on the remaining teeth, but several studies question if a causal relation actually exists. The more recent studies do show that loss of molars lead to increased wear on premolars. A pilot study on determination of the type of dynamic occlusion using wear facets on casts lead to the conclusion that the presence of wear facets do not ensure correct classification of lateral guidance schemes. Clinical assessment of occlusion during lateral movements is done with shim stock foil (12 μm), but the body position of the patient is of influence; occlusal contacts can differ when the body is tilted from an upright position towards a lying position. Both researchers and clinicians should apply this finding in their study design or treatment protocols.

Chapter 4 indicated that no evidence was found concerning threshold values for the (restorative) treatment of tooth wear. More recent papers suggest subjective reasons such as pain, impaired function or aesthetics. The only objective reason seems the pace of progression, underlining the importance of recording the amount or severity of tooth wear. Apart from the use of an index, quantitative systems have been developed in the last decades. These systems have mainly been applied to quantify the wear of restorative materials in in vitro studies. The available, applicable software did not allow analysis of three-dimensional scans, which lead to the decision to use two-dimensional scans (acquired with the use of a flat-bed scanner). Sets of casts with a three-year interval were used. Two studies in which the calibration and application of this two-dimensional system is applied, show that the method is accurate, reproducible and clinically applicable, but that interpretation and translation to other systems is difficult. Although the use of intra-oral scanners has advanced, the software to match surfaces is still developing. Apart from possible migrations of teeth, the lack of reproducible reference points causes problems and uncertainty in superimposing scans.

The results of the pilot-study showed that progression of attrition facets did not occur in the same magnitude per se. Limitations in the recording technique could explain the differences, but the results of the laboratory study described in chapter 8, indicate that frictional wear can result in wear scars that have a large variety in size. Differences in mechanical properties, enhanced by differences in layer thickness and prism orientation are possible explanations. The significant effects on tooth wear that were found in the pilot-study were *Canine Angle classification*, *horizontal overjet*, and *anterior guidance*. Interpretation of the results should be done with caution, as the study population was a sample of 28 students. The majority of other longitudinal studies assessing tooth wear consist of thirty participants or less. Conclusions should not be extrapolated, and conclusions about the role of occlusion in tooth wear are limited.

In conclusion it can be stated that:
- The prevalence of severe tooth wear is increasing during life, ranging from about 3% at age 20 to 17% at age 70. A strong correlation with age was found.
- There is no indication that prevalence of tooth wear has globally increased during the last decades.
- The role of occlusion in the process of tooth wear is limited, since no evidence was found justifying the qualification of certain occlusion-based interventions above others in the management of attrition.
- Body position is of influence in measuring tooth contacts during dynamic occlusion.
- Measurement of tooth wear using a 2-D method can be done precisely and accurately.
- In the sample of young adults described in this thesis, anterior protected articulation and horizontal overbite had an effect on the progression of occlusal tooth wear.

Inleiding

Aangezien ziekteprocessen zoals cariës en parodontale aandoeningen beter onder controle zijn dan in het midden van de vorige eeuw, en sindsdien meer mensen ook op hogere leeftijd hun tanden behouden, is gedurende de laatste decennia de slijtage van tanden en kiezen een fenomeen dat meer aandacht is gaan vragen in de tandheelkundige literatuur. De vraag is daarom gerechtvaardigd of slijtage een toenemende prevalentie heeft.

Bij het beschrijven van slijtage worden verschillende mechanismen onderscheiden. Chemische aantasting met weefselverlies als gevolg wordt *erosie* genoemd, terwijl de mechanische slijtage door frictie van gebitselementen onderling *attritie* genoemd wordt, of *abrasie* waar een ander materiaal dan een gebitselement de slijtage veroorzaakt.

De hoeveelheid slijtage verschilt van persoon tot persoon, en zal toenemen naar gelang de leeftijd vordert. Om dit in kaart te brengen wordt gebruikt gemaakt van een zogenaamde *tooth wear index;* een *kwalitatieve* meet methode. Er zijn verschillende soorten indices beschikbaar, elke met een eigen schaalverdeling. Naast het gebruik van een index kan slijtage ook *kwantitatief* gemeten worden; hiervoor worden naast foto-technieken vooral scanners in combinatie met software voor analyse van de verschillende opeenvolgende stadia van slijtage op gebitsmodellen gebruikt.

Welke niveaus van slijtage aanleiding zouden moeten geven voor interventie blijkt een lastige vraag. De literatuur verstrekt daar weinig informatie over. Over het nastreven van een bepaald occlusie-schema daarentegen is wel veel literatuur, maar vooral ook veel discussie te vinden. De stromingen die verschillende occlusie-schema's verdedigen worden gepresenteerd vanaf de jaren '60, en de vraag wordt gesteld of het concept van hoektandgeleiding in het kader van slijtage en preventie van slijtage een bewezen effect heeft.

Het onderzoek dat in dit proefschrift beschreven wordt beperkt zich tot het analyseren van het mechanisme van slijtage, en gaat niet in op de behandelstrategie. De prevalentie van slijtage bij volwassenen en kinderen wordt door middel van een systematische review in kaart gebracht, evenals de gepubliceerde onderzoeken die gaan over de samenhang tussen attritie met occlusie, dysfunctie, en interventie.

Daarna worden de methode van het vastleggen van occlusie, het meten van slijtage en de meetgegevens van een pilot-groep geanalyseerd. De algemene discussie behandelt de verzamelde gegevens en vergelijkt deze met de onderzoeksresultaten die inmiddels na het publiceren van de artikelen uit dit proefschrift zijn verschenen.

Hoofstuk 2

Het doel van dit onderzoek is het verzamelen van gegevens over de prevalentie van slijtage bij volwassenen, gepubliceerd vanaf 1980 tot en met medio 2007. Hiervoor is een digitale zoektocht uitgevoerd, waarbij verschillende sets van zoektermen zijn gebruikt: "tooth + wear"; "dental + attrition + prevalence"; "dental + wear + prevalence"; "erosion + prevalence"; and "abrasion + prevalence". Twee gekalibreerde onderzoekers hebben de gevonden artikelen onderzocht en van de 186 artikelen die geïncludeerd werden, bleken er uiteindelijk 13 bruikbaar voor analyse. Omdat de gebruikte indices in de primaire studies niet vergelijkbaar waren, werden de gerapporteerde prevalentiecijfers zo veel als mogelijk omgerekend, om prevalentie vergelijkbaar te maken. Daarbij werd gekozen voor de *Tooth Wear Index* (TWI) zoals geïntroduceerd door Smith en Knight.

Vier artikelen konden worden gebruikt voor een regressieanalyse tot op tandniveau, en drie op persoonsniveau. Zes studies lieten zien dat mannen meer slijtage vertonen dan vrouwen. Er kan geconcludeerd worden dat de prevalentie van gevorderde slijtage gedurende het leven toeneemt van ongeveer 3% op 20 jarige leeftijd tot 17% bij de 70 jarigen. Er werd een significante correlatie met de leeftijd gevonden.

Hoofdstuk 3

In dit onderzoek werd naar analogie van de methode van hoofdstuk twee, een zoektocht uitgevoerd naar de prevalentie van gebitsslijtage onder kinderen en adolescenten. Hierin konden 29 artikelen werden geïncludeerd, waarbij de gegevens van in totaal 45186 personen werden gecombineerd. Naast prevalentie en leeftijd, werden ook geslacht, socio-economische status (SES), fluoridering en dieet geïncludeerd in de analyse. Het analyseren van de slijtage in een gebit met zowel melkelementen als blijvende gebitselementen bleek niet zondermeer mogelijk, en de gerapporteerde prevalentie vertoonde veel spreiding: zo werd een prevalentie van 0-82% gerapporteerd. Om analyse mogelijk te maken werd gekozen voor een dichotomie waarbij dentine-expositie gold als omslagpunt naar gevorderde slijtage.

Melkelementen en blijvende elementen zijn apart geanalyseerd. Het gebruikte regressiemodel vond wel een significante correlatie met leeftijd voor melkelementen van kinderen tot een leeftijd van 7 jaar, maar niet voor de blijvende elementen van oudere kinderen en adolescenten. Correlaties met geslacht, SES, fluoridering en dieet waren zodanig uiteenlopend, dat daaruit geen conclusies getrokken konden worden.

Hoofdstuk 4

Om te onderzoeken of attritie gecorreleerd is met occlusale factoren, kauwfunctie en dysfunctie, is een systematisch literatuuronderzoek uitgevoerd. De uitkomsten hiervan zouden ondersteunend kunnen zijn voor het opstellen van behandelprotocollen in gevallen van attritie. Een elektronische zoektocht via Pubmed met de zoektermen 'tooth' en 'wear', gepubliceerd vanaf 1980 tot en met 2006, leverde 1289 studies op, waarvan er na selectie 33 overbleven. Voor deze selectie, beoordeelden twee gekalibreerde onderzoekers onafhankelijk van elkaar de titels en samenvattingen. Reviews, studies over dierlijk tandmateriaal, laboratoriumstudies, case-reports, forensische of historische studies en studies die niet in Engels waren gepubliceerd, werden uitgesloten.

Analyse van de 33 studies die overbleven nadat gefocust werd op occlusale factoren, functie en dysfunctie, interventie en attritie, kon geen wetenschappelijk bewijs vinden voor het aanbevelen of opstellen van een behandelprotocol of occlusie-concept voor de behandeling van attritie. Er waren geen studies die aantoonden dat de afwezigheid van posterieure gebitselementen perse leidt tot meer slijtage, echter één studie toonde aan dat de slijtage van de overgebleven gebitselementen hoger is bij een lager aantal elementen. Bruxisme en attritie werden vaak samen gevonden, maar studies over ‘TMD signs and symptoms’ en attritie verklaarden de relatie tussen atritie en bruxisme of TMD niet. Studies over drempelwaarden van slijtage waarbij behandeling noodzakelijk zou zijn, konden evenmin gevonden worden.

Hoofdstuk 5

In deze pilotstudie werd onderzocht of occlusale contacten bij laterale kaakbewegingen beïnvloed worden door de lichaamshouding. Dertig studenten en tweeëntwintig stafleden lieten de occlusale contacten tijdens laterale kaakbewegingen vastleggen met behulp van articulatie-folie, waarbij de behandelstoel in drie standen werd geplaatst: liggend, half zittend en rechtop-zittend. De gevonden occlusale contacten werden geclassificeerd als groepsfunctie, hoektandgeleiding en frontgeleiding. Occlusale contacten aan de werkende zijde evenals de niet-werkende zijde werden geanalyseerd. Bij 96% van de deelnemers werden na houdingsverandering ook veranderingen gevonden in de tandcontacten; de houdingsverandering leidde bij 10% tot 17% tot verandering van classificatie van het occlusiepatroon.

Hoofdstuk 6

Het doel van deze studie was het onderzoeken van een twee-dimensionele analyse van slijtage door gebruik te maken van een flat-bed scanner. Hiervoor werden gipsen gebitsmodellen met het kauwvlak op een flatbed scanner geplaatst. De scans hiervan werden gebruikt voor metingen.

Twee onderzoekers (A en B) gebruikten onafhankelijk van elkaar meet-software om de vooraf aangetekende slijtage facetten op tanden en kiezen op te meten, door met een muis de randen van de facetten aan te geven. De metingen van 10 gebits-modellen met in totaal 218 tanden en kiezen werd herhaald om meetfouten (DME; duplicate mearsurement error) op te kunnen merken. De twee onderzoekers bleken vergelijkbare en consistente resultaten te vinden: correlaties van 0,998-0,999 en een DME van 0.15 mm^2 (onderzoeker A) en 0.30 mm^2 (onderzoeker B). De metingen en DME’s op fronttanden weken niet af van de metingen op (pre) molaren.

In het tweede deel van het onderzoek werd het optekenen en vervolgens opmeten van facetten op 70 tanden en kiezen door twee andere onderzoekers (C en D) gedaan.

Daarbij werden twee sets modellen gebruikt voor beide onderzoekers, waarbij zowel het optekenen als opmeten van facetten werd geanalyseerd. Hierbij werden grotere DME's gevonden (0,27mm² en 0,39mm²); onderzoeker D vond significant hogere waarden bij de meting op het tweede model. Onderzoeker C was consistenter in het optekenen, maar bij vergelijking van de DME waren de onderzoekers vergelijkbaar (C: 0.27 mm² en D: 0.39mm²).

De conclusie is dat optekenen van slijtagefacetten op gipsen modellen en opmeten met behulp van een flatbed scanner accuraat en reproduceerbaar kan worden gedaan: er werd een goede intra- en inter-beoordelaar overeenkomst gevonden.

Hoofdstuk 7

In deze studie werd de progressie van slijtage in een groep jong volwassenen geregistreerd met behulp van de methode zoals beschreven in hoofdstuk 6. Daarbij werd door 28 tandheelkunde studenten medewerking verleend door gebitsmodellen te laten vervaardigen met een interval van drie jaar. Daarnaast werden occlusale factoren en anatomische eigenschappen in kaart gebracht en het type geleiding vastgesteld zoals beschreven in hoofdstuk 5. Door middel van regressieanalyse werd onderzocht wat de correlatie van toename van slijtage is met de volgende occlusale factoren: 'type geleiding', verticale overbeet', 'horizontale overbeet', 'diepte van de sagittale curve', 'Angle classificatie bij de hoektand', 'orthodontische behandeling in het verleden' en 'zelf vastgesteld knarsen / klemmen'.

De gemiddelde toename in oppervlakte van de slijtagefacetten varieerde van 1,2 mm² bij premolaren en incisieven, tot 3,4 mm² bij molaren. De relatieve toename in oppervlakte bedroeg 15 tot 23%. De absolute toename van slijtage in de bovenkaak bleek groter dan de toename in de onderkaak , behalve bij molaren.

Door middel van *backward regression* werd voor de parameters 'groepsfunctie', verticale overbeet', 'diepte van de sagittale curve', 'orthodontische behandeling in het verleden' en 'zelf vastgesteld knarsen / klemmen' vastgesteld dat er geen significante relatie gevonden was voor deze variabelen met toename van slijtage.

Het uiteindelijke multipele lineaire regressiemodel liet significante negatieve associaties zien van toename van slijtage in groepen elementen (molaren, premolaren, frontelementen) met 'frontgeleiding' en 'horizontale overbeet'; minder toename van slijtage in personen met frontgeleiding of een grotere horizontale overbeet. Wanneer alle elementen worden samengevoegd, heeft ook 'zelf vastgesteld knarsen / klemmen' geen significant effect voor toename van attritie en bleef alleen 'frontgeleiding' als significante factor over.

Geconcludeerd kan worden dat binnen deze beperkte onderzoekspopulatie er een significante associatie was tussen toename van slijtage enerzijds en het aanwezig zijn van frontgeleiding of de grootte van de horizontale overbeet anderzijds. Voor klemmen of knarsen werd geen significant effect gevonden voor toename van attritie.

Hoofdstuk 8

Dit onderzoek had als doel te onderzoeken of de slijtage van natuurlijk glazuur in een tribologie-opstelling te simuleren is. Hiervoor werd een bolvormig stuk en een volledig glad stuk glazuur gemaakt uit één stuk humaan tandmateriaal. Deze delen zijn in een testopstelling geplaatst waarbij de bol een vastgesteld aantal bewegingen over het gladde oppervlak maakte met gecontroleerde belasting en snelheid. Als referentie werd dezelfde test uitgevoerd met behulp van een stalen kogel op stalen oppervlak. De slijtagegroeven die zijn ontstaan in het vlakke deel werden door middel van een interferentie-microscoop opgemeten.

Van de negen paren glazuur-stukken konden twee sets niet worden geanalyseerd; bij één kon niets worden opgemeten omdat slijtage door de glazuurlaag heen was gegaan tot in het dentine waardoor de slijtagegroef te dipe was om op te meten met de interferentiemicroscopp. Bij één bleek de glazuurlaag verdwenen aan de kant van de bol waardoor dentine werd uitgesmeerd over het gladde glazuuroppervlak. Van de overgebleven zeven paren die konden worden opgemeten bleek dat er een slijtagegroef was ontstaan van gemiddeld 50 µm breed en 0,5 µm diep. De variatie in het volume dat afgesleten was varieerde van $7{,}3 \times 10^{-6}$ mm^3 tot $1{,}1 \times 10^{-4}$ mm^3. De stalen kogels lieten bij dezelfde testopstelling meer slijtage ontstaan, maar de variatie in volume was klein.

Geconcludeerd werd dat een in-vivo tribologische set-up om attritie te simuleren erg lastig te standaardiseren is, mogelijk door variatie in de eigenschappen van het biologisch materiaal. De dikte van de glazuurlaag en de oriëntatie van prismata tijdens belasten kunnen een rol spelen in het optreden van de variatie.

Hoofdstuk 9

In de *general discussion* worden de methoden en bevindingen van de verschillende onderzoeken in relatie tot elkaar beschreven en wordt besproken wat hierover aan nieuwe feiten beschikbaar is gekomen.

Aangaande de vraag of de prevalentie van slijtage stijgend is, moet geconcludeerd worden dat de geïncludeerde studies uit hoofdstuk 2 en 3 geen bevestiging geven van een stijgende prevalentie. De variatie van gerapporteerde prevalentie is groot, van 1 tot 77%, en de meer recente studies dan de geïncludeerde studies, rapporteren geen hogere prevalentie. Bij de beoordeling van de meer recente prevalentiestudies zal naast een kritische analyse van de gebruikte index of meetmethode, ook het land waarin de studie is uitgevoerd, als relevante factor moeten worden gewogen.

Hoewel de samenhang tussen type occlusie en slijtage op grond van onderzoeks-gegevens grotendeels ontbreekt, worden in case reports wel aanbevelingen gedaan voor het te bewerkstelligen occlusie patroon (of schema). Hoektandgeleiding heeft vanuit een restauratief perspectief voordelen aangezien het voorspelbaar te bereiken is. Het wordt in casuïstiek vaak als doel beschreven. De review in hoofdstuk 4, evenals de recentere reviews ondersteunen dit echter niet. Een tweede veronderstelling, dat klemmen of knarsen (bruxisme) niet alleen slijtage veroorzaakt maar ook kaakgewrichtsklachten (Temporomandibular dysfunction; TMD), wordt in de literatuur evenmin ondersteund. De conclusie van een recente review, waarin een relatie tussen het occlusie patroon en het optreden van TMD betwijfeld wordt, leidt samen met de bevindingen van hoofdstuk 4 tot de conclusie dat, bruxisme, TMD, en het occlusiepatroon met het optreden van slijtage een complexe, maar niet causale, relatie hebben.

Het lijtk aannemelijk dat er bij functioneren met minder tanden en kiezen meer slijtage zal optreden, maar er zijn diverse studies die deze causale relatie in twijfel trekken. De meer recente studies laten echter wel zien dat bij het ontbreken van molaren er meer slijtage op de premolaren te zien is.

In een pilotstudie werd gevonden dat het bepalen van het type occlusiepatroon niet met voldoende zekerheid gedaan kan worden door alleen de aanwezige slijtagefacetten op gebitsmodellen te beoordelen. De klinische beoordeling van het occlusiepatroon wordt met behulp van dunne shim stock folie (12 µm) gedaan, maar de positie van patiënt in de behandelstoel is daarbij van invloed. In liggende ontstaan veelal andere occlusale contacten tijdens articuleren dan wanneer een persoon rechtop zit. Zowel onderzoekers als behandelaars zouden deze bevinding moeten meenemen in de opzet van onderzoek en behandeling.

In de systematische reviewstudie naar attritie, occlusie en (dys)functie om inzicht te verkrijgen over het moment van (restauratieve) interventie, bleek de literatuur daarvoor geen aanknopingspunten te bieden. Recentere reviews suggereren vooral subjectieve redenen zoals pijn, verstoorde functie of esthetiek. De enige objectieve reden (voor interventie) is een *te grote* progressiesnelheid, daarom is het cruciaal om de progressie vast te kunnen stellen. Naast het gebruik van een index om de progressiesnelheid van slijtage in kaart te brengen zijn er de laatste decennia meerdere kwantitatieve systemen ontwikkeld, waarvan de meerderheid voornamelijk gebruikt zijn voor het opmeten van slijtage van restauratie-materialen in laboratorium-studies. De software die aanwezig was tijdens dit promotieonderzoek liet geen analyse toe van drie-dimensionele scans, waardoor besloten werd twee-dimensionele scans (gemaakt met behulp van een flat-bed scanner) te analyseren van sets gebitsmodellen met een interval van drie jaar. De twee studies uit hoofdstuk 6 en 7 waarin deze methode wordt gekalibreerd en in een pilotgroep toegepast, laten zien dat de methode reproduceerbaar, accuraat en klinisch bruikbaar is, maar interpretatie en vertaling naar andere meetsystemen blijft lastig. Hoewel de ontwikkeling van intra-orale scanners gevorderd is, blijkt software om de progressie van slijtage vast te stellen, nog (steeds) in een fase van ontwikkeling. Naast de mogelijke migraties van tanden en kiezen vormt het ontbreken van reproduceerbare referentiepunten een onzekerheid bij het superponeren van scans.

De resultaten van de studie in hoofdstuk 7 laten zien dat progressie van attritie-facetten bij antagonerende gebitselementen niet perse in dezelfde mate optreedt. De beperkingen van de gebruikte meettechniek zou een verklaring zou kunnen zijn, maar de bevindingen van de laboratoriumstudie zoals beschreven in hoofdstuk 8, tonen aan dat er grote variatie kan zijn in slijtage bij frictie van twee dezelfde stukken glazuur. Verschil in mechanische eigenschappen, versterkt door verschillen in laagdikte en oriëntatie van glazuurprismata zijn mogelijke verklaringen hiervoor.

In de pilotgroep van de longitudinale studie naar attritie zijn significante effecten op de progressie van slijtage gevonden, te weten: *Angle-classificatie* / *horizontale overbeet* en *frontgeleiding*. Er is voorzichtigheid geboden bij de interpretatie van deze bevindingen over occlusie en slijtage in de pilotgroep, aangezien er slechts 28 deelnemers waren. De meerderheid van andere longitudinale studies over slijtage bestaat echter ook uit dertig personen of minder. Extrapolatie daarvan, en conclusies aangaande de rol van occlusie bij slijtage zijn dan ook beperkt.

Samengevat kan worden geconcludeerd:
- De prevalentie van slijtage hangt sterk samen met leeftijd, en varieert van ongeveer 3% ernstige slijtage op 20 jarige leeftijd, tot 17% op 70 jarige leeftijd.
- Er is geen indicatie voor een wereldwijde stijging van de prevalentie van slijtage.
- De rol van occlusie bij de ontwikkeling van slijtage is beperkt, er is geen onderzoek dat aantoont dat een bepaald occlusieconcept beter is dan anderen in het managen van slijtage.
- De lichaamshouding blijkt van invloed op de occlusale contacten tijdens laterale kaakbewegingen.
- Het vastleggen van occlusale slijtage met een 2-d methode is reproduceerbaar en accuraat uit te voeren
- In de pilotstudie is een effect gevonden van frontgeleiding, Angle classificatie en horizontale overbeet op de progressie van slijtage.

11

Dankwoord (Nederlands)

Dankwoord

Beste Nico, dankjewel dat je me deze kans hebt geboden. Je hebt waarschijnlijk, net als velen, op een gegeven moment gedacht dat het niet meer tot een promotie zou leiden. Toch heb je de deur open gehouden. Dat je me in 2006 naar Zwitserland meenam, en tussen de auteurs van de grote boeken in onze bibliotheek zette voor het schrijven van een review, heb ik als heel bijzonder ervaren. David noemde dat terloops in een discussie: je geeft jonge, beginnende mensen de kans ook op een podium mee te kunnen doen. Dat enthousiasmeerde, evenals de congressen waar je mij samen met collegae naar toe liet gaan. Het boekje is af, maar hopelijk is het boek niet uit. Nogmaals dankjewel!

Beste Cees, bescheidenheid, geduld en doorzettingsvermogen, en vermogen tot scherp analyseren en accuraat formuleren zijn denk ik een paar van jouw eigenschappen waarmee je bij mij, en bij vele anderen, indruk maakt. Ik heb vaak met jou zitten praten over dit onderzoek, de gekozen invalshoeken, maar ook hoe anderen daar totaal anders over kunnen denken. Dat wij vaak op dezelfde lijn zaten en zitten, deed me goed; de wirwar aan meningen in de literatuur kan immers ook voor verwarring en demotivatie zorgen. Als fanatieke watersporter ken je natuurlijk alle uitdrukkingen die een proces van onderzoek en promotie kunnen beschrijven, daarom neem ik je bij deze die wind uit de zeilen. Ook jij hebt na veel geduld, voor mij het gesprek over de inhoud en het proces van afronden open gehouden. Dankjewel daarvoor.

Dear David, the first time that I had to give a presentation in Australia, you asked me whether I believed in ‘abfraction’. My answer was ‘I used to be a believer’. This was because of your work on this topic. You, together with Nico and Cees, taught me to go for the facts, and leave the opinions as they are. This was your approach in the systematic reviews as well. Nevertheless, we are allowed to have opinions! The last time we met, you mentioned the review on prevalence in a lecture, and stated ” this work was performed in cooperation with the group in Nijmegen: Nico, Cees, and Arie… who still has not finnished his PhD…”. Well it appears that finally I managed to! Thank you for all your advice, cooperation and support.

Dear Jose, during the first paper that we worked on, you were fascinated by of the word ‘scrutinize’. We had some laughs about it, and kept that spirit in the work that followed. Your experience in impression materials, the analysis and technique of scanning really impressed me. It felt familiar when we met again in Torino, I really do hope that we meet again in future events.

Beste Ewald, ik ben de zoveelste in rij, die niet alleen ruimschoots toegeeft dat ik van de statistiek maar een heel klein beetje beheers, maar ook veel bewondering heb voor jouw inzicht en vaardigheid om razendsnel analyses te doen. Zonder jouw input (en geduld met onze beperkingen) was dit er niet. Dankjewel!

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Beste Marc, hoewel de periodes met radiostiltes groter zijn geweest dan de termijn van daadwerkelijk samenwerken, heb je met het project dat we samen gedaan hebben in Enschede bijgedragen aan een proefschrift dat voor techneuten (je eigen woorden…) misschien een 'ver van hun bed show' is. Desondanks was je, ook nog heel recent, oprecht geïnteresseerd en bereid te ondersteunen; dankjewel daarvoor!

Beste Rob en Dick, vanaf het eerste jaar als student, maar later als collega-docent en als onderzoeker, heb ik van jullie geduldige, maar ook stug doorwerkende (diesel-) houding veel geleerd en ik ben niet de enige die vermoed dat het zonder jullie peptalk nog wel even had kunnen duren voordat het boekje af was. Dick jij hebt het vermogen, in tegenstelling tot veel wetenschappers, om complexe materie zo te ordenen en te presenteren dat het heel overzichtelijk en zelf begrijpelijk wordt. Daarnaast kun je de vertaalslag naar de praktijk of patiënt net zo overzichtelijk maken. Ik heb daar veel respect voor, en hoop dat we elkaar nog lang (hierin) tegen kunnen komen. Rob, jij hebt je met precies de juiste hoeveelheid druk, als een luis in mijn pels gevestigd om ervoor te zorgen dat de deadlines nu ook echt gehaald werden (ook al was er wat scepsis…). Je begreep als geen ander dat met twee part-time banen, een opgroeiend gezin en af en toe een verbouwing, de afleiding en chaos zo groot kan zijn, dat zo'n externe coach (zelf vanuit Spanje) essentieel is. Je hebt ook willen optreden als paranimf, de ultieme professionele en persoonlijke steun in de rug; dankjewel daarvoor!

Collega's van de uni,
In de jaren dat ik onderzoek kon doen, hebben jullie onderwijs en patiëntzorg gecontinueerd; dat was voor mij een bevoorrechte positie, waarvan ik me bewust was en ben. Dankjewel, ook voor het meewerken aan de afdrukken en occlusieanalyses, en niet in de laatste plaats voor de interesse en steun.

Collega's uit de praktijk
Wibro en Rita; jullie hebben me de kans gegeven om parttime in een fijne praktijk te werken, waarin zorg en respect voor patiënten op de eerste plaats stond. Dat onze

wegen na zeven jaar uit elkaar gingen, was gelukkig niet het gevolg van onenigheid. Dankjewel voor deze kans en jullie steun en betrokkenheid. Rolf en Gerrit; vooral in het begin heb ik jullie hulp mogen inroepen voor met name een extractie die niet lukt; dankjewel voor die collegialiteit! Anja en Paula, jullie hebben me heel praktisch geholpen, en we hebben fijn kunnen samenwerken. Het doet dan ook elke keer weer goed als we elkaar (in de huidige praktijk) weer tegenkomen.

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Beste Joost, We kennen elkaar nu bijna 25 jaar. In die 25 jaar zijn we deels parallel en deels anders ontwikkeld, maar hebben toch veel behouden wat ons bindt. Dankjewel voor jouw vriendschap, steun en advies; dankjewel voor het willen optreden als paranimf. We gaan weer zeilen zodra dit afgerond is! Agnes, dankjewel voor het af en toe ter beschikking stellen van je vent voor het zeilen en klussen!

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Lieve Ter Horsten en aanhang,
Ook al wordt weleens schertsend iets over koude kant gezegd, jullie zijn en blijven een warme club. Bijna net zo lang als jullie mij kennen ben ik al bezig met dit onderzoek, en nu wordt dan eindelijk het moment gevierd dat het af is. In die tijd is er binnen de familie natuurlijk veel gebeurd dat qua prioriteiten terecht boven dit onderzoek uitsteeg, maar ondanks dat hadden jullie nog steeds interesse en steun voor mij, bedankt daarvoor!

Lieve, liefste, allerliefste Nienke, Bart, Thijs en Onno,
Afgelopen maanden heb ik soms een kort lontje gehad, en ging veel tijd achter de laptop voorbij. Dat ik er tijdens het eten of familiebezoek niet altijd met mijn hoofd bij was, of toch nog thuis verder moest terwijl jullie op pad gingen, komt hopelijk nu tot een einde. Jullie zijn ondanks het tijdelijke verschuiven van aandacht, echt mijn prioriteit! Nienke, dankjewel voor je geduld met me, je steun, (lange termijn-) vertrouwen en praktische hulp met het formuleren van correct Engels. Ik ga ervan uit (en hoop) dat mijn gezeur over artikelen die het volgens mij niet bij het goede eind hebben, nu weer een beetje uitdooft. We gaan met zijn allen vrolijk en dankbaar verder!

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Currirulum Vitae

Currirulum Vitae

English

Arie van 't Spijker was born in South Africa on May 9th, 1974. He attended the primary school in Sibasa, South Africa. In 1987 his family moved to the Netherlands. Secondary school was attended at Leerdam and Gorinchem. He started to study dentistry at the KU Leuven (Belgium) in 1993, and continued the study at the KU Nijmegen from 1994; graduation was in 1999. He took part in an exchanges program with the University of Bern (Switzerland).

He sarted to work as a part-time instructor at the Nijmegen dental school from january 2000 up to today, and as general dental practicioner in group-practices in Oosterbeek (2000-2006), Ewijk (2007-2010) and is currently working at the Gezamenlijke Tandarts-praktijk in Nijmegen.

Arie is married to Nienke ter Horst, and father of Bart (2010), Thijs (2012) and Onno (2014).

Nederlands

Arie van 't Spijker is geboren te Soutpansberg, Zuid Afrika op 9 mei 1974. Hij doorliep de basisschool te Sibasa, Zuid Afrika (Laerskool Bergvlam). In 1987 verhuisde het gezin naar Nederland. Van 1987 - 1993 is de Middelbare school te Leerdam (Prins Willem Alexander college) en Gorinchem (Chr scholengemeenschap Oude Hoven) bezocht, waarna in 1993 de Studie Tandheelkunde aan de Katholieke Universiteit Leuven (Belgie) startte. In 1994 werd deze voortgezet aan de Faculteit Tandheelkunde aan de Katholieke Universiteit Nijmegen, en afgerond in 1999. Tijdens de studie was er een buitenland-stage naar de Universiteit Bern (Zwitserland).

Vanaf 2000 tot heden werk hij als parttime tandarts-docent en onderzoeker op de faculteit Tandheelkunde van de KUN, later UMCN St Radboud, en heden Radboud*umc* Nijmegen. Daarnaast werkte hij parttime als tandarts algemeen practicus in een groeps-praktijk te Oosterbeek (2000-2006), Ewijk (2007-2010) en vanaf 2010 tot heden in de Gezamenlijke Tandartsenpraktijk Nijmegen.

Arie is getrouwd met Nienke ter Horst, en vader van Bart (2010), Thijs (2012) en Onno (2014).